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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ANAEROBIC POWER ASSESSMENT IN FEMALE ATHLETES submitted by CHRISTINE CLARK in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

Dedicated to my parents

ABSTRACT

This study was designed to examine the feasibility of using one or more anthropometric and/or physiological measures to develop procedures to predict the resistance required to elicit both peak power output (PPO[R]) and maximal power output (MPO[R]) on a Monark bicycle ergometer. Twenty-four highly anaerobically trained female athletes (Basketball [n = 6], Volleyball [n = 7], Gymnastics [n = 5], Cycling [n = 3], Track/Field [n = 3]) completed a series of '30 second' all-out bicycle ergometer tests to establish the resistance required to elicit peak power output (PPO) and maximal power output (MPO). Both peak power output and maximal power output were significantly higher than the weight-relative Wingate protocol. Test-retest data proved reliable ($p < 0.05$) and two regression equations were developed utilizing thigh circumference (TC), calf circumference (CC) and body weight (WT) as predictors: $PPO(R) = 1.2899 + 0.1836(TC) - 0.2378(CC) + 0.0301(WT)$ with a multiple R of 0.709 ($p < 0.05$) and $MPO(R) = 0.8624 + 0.1316(TC) - 0.1502(CC) + 0.03511(WT)$ with a multiple R of 0.726 ($p < 0.05$). The equations were not applicable for the endurance athletes tested (n = 4) but the power test was proven to be anaerobic in nature as shown by venous blood lactic acid levels. To optimize the power output (both MPO and PPO) for an individual an optimal combination of resistance setting and pedal speed was necessary and appeared to be sport related.

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CHAPTER I

INTRODUCTION

Information regarding the male athlete and his performance as it relates to utilization of the body's energy systems is abundant. Until recently males have predominated as participants in the athletic realm and their excellence in part may be due to knowledge gained from research. For the female athlete, however, changing social attitudes have allowed her to venture into this realm but with much fewer scientific foundations to draw upon. Thus research which exposes more knowledge of athletic performance in females specifically, must help to expand the already existing body of knowledge and confirm the applicability of male oriented research on the female population.

Any physically demanding event requires both skill and co-ordination on the part of the performer but this however does not totally guarantee a good performance. The efficient utilization of the energy systems, as well as optimizing force/velocity relationships through manipulation of training, may be crucial to optimizing the elite athlete's performance. Heredity, also appears to be an overall determining factor in performance capacity.

Of particular interest is the contribution anaerobic metabolism makes to short duration, high intensity performances since the interplay of the ATP-PC system and anaerobic glycolysis is primarily dependent upon the duration and intensity of the activity. With regard to an individual's maximal anaerobic work performance, one must keep in perspective the range of different anaerobic events that exist and the problems associated with devising an all encompassing anaerobic power test. That two different ATP sources can contribute to performance to

varying degrees certainly suggests defining anaerobic work performance would be difficult because two sources of ATP contribute to performance. To examine a test protocol that gives some insight into performance, and perhaps metabolic function, over the anaerobic time course seems beneficial.

Certainly intensity of an anaerobic power test (resistance and frequency) and time frame, as functions of production of peak or maximal power output, should be examined very closely. Some questions may arise from this examination as to what anaerobic power really represents. Is anaerobic power the ability to: (1) elicit a high single response, such as a single contraction, or (2) elicit a high but sustained performance over the anaerobic time course, or (3) to perform a series of high intensity bursts of power output with short or long recovery intervals?

STATEMENT OF THE PROBLEM

The purpose of this study was to examine the feasibility of using one or more anthropometric and/or physiological measures to develop procedures to predict the resistance required to elicit both peak power output and mean maximal power output on a bicycle ergometer. Of particular interest was performance capabilities of highly anaerobically trained female athletes on this test in relation to the anaerobic nature of the specific sport. Thus, not only was ability to sustain exercise over a thirty second time frame examined but also mean maximal or peak power output each 5 seconds of the 30 second test. An examination of the relationship between resistances to elicit peak and maximal power output was examined and venous blood lactates were taken to aid in identification of the time-course relationship for anaerobic sources during the 30 second exercise bout at the resistance to elicit peak

power output.

The following questions were also examined:

1. Does the expedient method developed by Evans and Quinney (1981) hold true for females?
2. Is maximal power output produced as measured by existing protocols?
3. Can maximal and peak power output be realiably determined for females?
4. What reflection do such measurements have on specificity of training?
5. Is the type of anaerobic training reflected in one's ability to produce peak or maximal total power output?
6. How do performances vary at resistances less than those which produce peak or maximal power output?
7. How do lactic acid concentrations reflect the utilization of energy sources, power output and training specificity?

HYPOTHESIS

It is hypothesized that regressions similar to those developed by Evans and Quinney (1980) can, by examination of leg skinfolds, leg girths, leg volumes, percent body fat, weight and power output results, be adopted to predict the resistance settings required to elicit maximal power output on the Wingate anaerobic power test for female athletes. To this end, the maximal power output for 30 seconds, peak power output in 5 seconds and venous blood lactates could elucidate an individual's ability to draw upon and economically utilize anaerobic sources according to the specificity of training and therefore make regression equations more functional in terms of providing information about the trained athletes' anaerobic metabolic strengths and weaknesses.

The null hypotheses for this study are:

H_0: $U_1 = U_2 = U_3 = U_4 = U_5$ where

U_1 = force to elicit maximal power output

U_2 = resistance to elicit peak power output

U_3 = R for the Wingate protocol

U_4 = predicted R to elicit maximal power output

U_5 = predicted R to elicit peak power output

and H_0: $U_6 = U_7 = U_8 = U_9 = U_{10} = U_{11}$ where

U_6 = Volleyball Power Output

U_7 = Gymnastics Power Output

U_8 = Basketball Power Output

U_9 = Track/Field Power Output

U_{10} = Cycling Power Output

U_{11} = Endurance Power Output

LIMITATIONS

This study was limited by the following:

1. Accuracy of Equipment: Despite the inherent accuracies the investigator made every attempt to standardize test procedures by calibrating the bicycle ergometer prior to each test and techniques for skinfolds, circumferences and leg volumes were undertaken as outlined by Ross (1981). Reliabilities of these measures can be found in Appendix C.
2. Environmental Conditions: The ergometer tests were administered in the same laboratory over a period of 6 weeks. Temperatures ranged from 19° to 24°C. For densiometric measures, water density ranged from 0.9956 to 0.9947 and room temperature was 24°C.
3. Motivational and Psychological Factors: All tests were carried out

with the subject in a two hour post-prandial state and all subjects were verbally encouraged in the same manner by the same administrator throughout testing. Psychological factors affecting performance would be those of perceived exertion and motivation. However, being from a highly trained population the subjects should have performed very close to maximal levels.

4. Specificity of the Task: The majority of subjects tested were from a non-cycling population except for the group chosen especially for their expertise. If cycling specialists show task specificity in superior performances then the results of the non-specialists could be accounted for in this manner.

DELIMITATIONS

This study was delimited to:

1. Twenty-eight female volunteers between the age of 17 and 27 years and active to well trained (Basketball, Volleyball, Track and Field, Cycling, Gymnastics and Endurance).
2. Systematized testing process which enabled homing in on peak power output.
3. Random selection of one subject from each training group for analysis of venous blood lactates at appointed intervals throughout the 30 second test and at rest.

DEFINITIONS

Modified Bicycle Ergometer: A stationary Monark bicycle which was calibrated to allow individuals to exercise at proportionate, incremental or fixed loads. Modifications included toe clips, two micro-switches, reinforced racing handlebars and upscaled resistance.

Anaerobic Energy: Anaerobic energy is the energy utilized from sources

other than the oxidative process and is highly dependent upon intensity and duration of the activity. At the onset of exercise availability of ATP for the purpose of performing work is largely derived from the ATP-PC system and anaerobic glycolysis. Subsequently either depletion of anaerobic substrates or the adaption of the aerobic system to work/exercise above the basal metabolic rate will cause reduced utilization of anaerobic energy sources. Work performed largely as a result of utilization of these energy sources is measured as the mechanical power output.

Peak Power Output (PPO): Measurement of power output for each 5 second interval of the 30 second test to determine the interval in which peak or highest power output occurred. This event usually appeared in the first 5 seconds of exercise and is believed to correspond to the splitting of phosphagens (ATP-PC system).

Maximal Power Output (MPO): The combination of maximal pedal frequency and resistance for an individual that will elicit the highest possible cumulative measure of mechanical work over a 30 second time frame. The power output for each 5 seconds of the 30 second test was totalled and a mean value taken.

PPO(R) and MPO(R): The resistance needed to elicit peak power output and maximal power output (e.g., PPO(5) indicates a resistance of 5 kp was needed to elicit peak power output).

Power Curve: The plotting of the relationship between power produced and corresponding frictional resistance for a range of resistances for each individual in order to determine the resistance that will elicit peak and maximal power output.

Peak Lactatic Acid: Blood sampled after 5 minutes post-exercise and analyzed for presence of lactate.

Wingate Force Setting: A relative resistance setting determined by multiplying body weight (kg) by 0.075.

Absolute Power Output: Raw scores without compensation for training status or weight.

Relative Power Output: Power output scores transformed to compensate for individual differences (especially weight or percent of performance relative to max).

Oxygen Deficit: Oxygen deficit reflects the inability of the aerobic system to supply or meet the oxygen requirement. This deficit above basal levels contributes to the oxygen debt.

Oxygen Debt: This is the oxygen consumption above the basal rate at the cessation of exercise. It represents both the metabolic adjustments to exercise (anaerobic metabolism) and metabolic adjustments to cessation of exercise (the resynthesis of depleted metabolites). The metabolic adjustments that take place during the first 2-3 minutes of cessation of exercise are those associated with the rapid decline of oxygen consumption and the simultaneous or concomittant replenishment of ATP and stored CP. This is known as the alactic debt component and is differentiated from the lactacid portion in that it does not involve removal or resynthesis of lactic acid. The elevated utilization of oxygen at cessation of exercise aids in providing the energy required to restore ATP-PC stores and remove lactic acid.

Leg Volume: The volume (liters) of water at 24°C displaced from a volumetric tank by the leg of the subject immersed up to insertion of the grasilis muscle at the pubic arch but no higher than the gluteal furrow and with the leg squared and straightened to the top edge of the tank.

Thigh Circumference (TC): The circumference (cm) of the thigh one centimeter below the gluteal furrow (see Appendix C-V).

Calf Circumference (CC): Circumference of the calf at its largest part (see Appendix C-V).

Thigh Skinfold (TS): The vertical skinfold (mm) of the thigh taken centrally and frontally on the thigh at the point of TC.

Calf Skinfold (CS): Vertical skinfold (mm) taken centrally and medially on the calf at the point of greatest circumference.

Percent Fat (% Fat): The body composition of the subject as determined by densitometry techniques (Brozek et al., 1963).

Fast Twitch Fibers (FT fibers): Fast twitch fibers are of two types; fast oxidative glycolytic (type IIa) and fast glycolytic (type IIb).

Slow Twitch Fibers (ST fibers): Slow twitch fibers are slow, oxidative (type I) fibers.

Lactic Acid Concentration ([LA]): The measure of venous blood lactate concentration (mg/100 ml) as a representative of anaerobic metabolism.

CHAPTER II

REVIEW OF LITERATURE

Many different tests have been developed to measure anaerobic power. Some measure impulse performances (Sargent, 1921; Sargent, 1924) or events lasting up to one second (Margaria et al., 1966), yet others measure events up to and in excess of two minutes (Katch et al., 1977; Ayalon et al., 1974; Evans et al., 1981; Withers, 1979). That different researchers have assessed anaerobic power differently certainly lends itself to the conception that different facets of anaerobic power contribute to performance and certainly suggests that no single test is empiric of metabolic processes though some may show better applicability. To this end, types of anaerobic power tests available to the researcher were examined as well as their applicability in determining anaerobic capacities in both males and females.

Tests Of Anaerobic Power

To address the problem of type of test and more specifically type of protocol Katch et al. (1977) have very adequately isolated and examined the testing of anaerobic power on the bicycle ergometer. The major concern in their study was to determine both the optimal frictional resistance and pedal frequency that would elicit a maximal response. They were also concerned with determining the time frame of such a test and deemed 40 seconds to be an adequate time frame for an all-out pedal frequency with a frictional resistance between 5.0 and 6.0 kp. The evidence supporting this conclusion was the fact that at the 40 second stage on the two minute bicycle ergometer test only 19% of maximal $\dot{V}O_2$ was being utilized and the greatest absolute amount of cumulative work

($kpm \cdot min^{-1}$) was accomplished in this time frame. Additionally, the correlation between successive 6 second time frames from the 40 second point onwards correlated highly, thus indicating no change in performance after that time. There is a suggestion that power output from a 40 second test is indicative of physiological capacities in supplying energy anaerobically (Saltin et al., 1971) rather than aerobically but does not help to quantify or clarify the contribution of energy from phosphagen splitting or anaerobic glycolysis. The trainability of the anaerobic system (Cunningham et al., 1969; Green et al., 1975) may be a large component in performance capacity.

From an historical standpoint, one must question whether tests, such as those developed by Sargent (1921) and Sargent (1924), are all encompassing as far as the physiological measurement of anaerobic capacity or energy systems involved at the onset of exercise and during the oxygen deficit phase of exercise.

At that time tests of aerobic capacity were the primary focus of investigation; the athletes of high intensity and short duration or impulse events were largely neglected. The innovative work of Sargent (1921) and Sargent (1924) led to the vertical or Sargent jump which provided a means for measuring anaerobic performance capacities, a basis for comparison amongst individuals and a means of comparing particular athletic populations.

Other impulse tests of anaerobic power utilized are the vertical power jump and the standing broad jump. These tests have been adapted to the specific needs of sports. For example, testing anaerobic power in the arms of a swimmer would seem more realistic than the legs.

Testing anaerobic power has changed dramatically since 1921 and

while the Sargent jump is still utilized, Margaria (1966) began to look at tests (stair run lasting 0-10 seconds) that taxed a greater portion of the anaerobic stores. Another short duration, non-impulse measurement is the 50 yard run.

Anaerobic power has also been measured on the bicycle ergometer and time frames for exercise have ranged from 20 seconds (Campbell et al., 1979), 40 seconds (Katch et al., 1977), one minute (Szogy et al., 1974), two minutes (Katch et al., 1977) and the two most recently examined bicycle ergometer tests lasting 30 seconds (Bar-Or et al., 1977 and Evans et al., 1981). A summary of the variety of anaerobic power tests utilized is found in Table I.

The latter two studies give substantial support to the examination of performance of the anaerobic athlete by utilization of anthropometric data to predict the workload on the bicycle ergometer that should be used to elicit a maximal response. This process would circumvent the multiple testing that is required to find the athlete's optimal resistance/rpm ratio remembering that speed and force are both anatomically limited.

Subsequently, analysis of not only performance over a 30 second period (which would correspond to a 200 meter sprint event, for example) but also multiples of the 5 second periods for performances could be examined as they relate to particular events. Hence, power output for the first 5 seconds of the 30 second test would shed light on possible performance ability in more impulse or short duration events whereas a time period of between 10 and 15 seconds would be more indicative of performance in the 100 meter sprint or hurdles event or short, high intensity efforts required in ice hockey (Green et al., 1975).

Examination of peak power output (0-5 seconds) and total power

TABLE I. Summary of Anaerobic Power Tests Available to the Physiologist

TEST	TIME	RESISTANCE	REPETITION	AUTHOR
Standing Jump	0- 1 sec	Body Wt	1 maximal	Sargent 1921
Stair Run	0- 5 secs	Body Wt	all out	Margaria 1966
Bicycle Ergometer	0-30 secs	0.075 x Body Wt	all out	Szogy et al., 1974
Bicycle Ergometer	0-30 secs	0.075 x Body Wt	all out	Bar-Or et al., 1977
Bicycle Ergometer	0-40 secs	4-6 kp	all out	Katch et al., 1977
Bicycle Ergometer	0-20 secs	1.5 x R at $\dot{V}O_2max$	all out	Campbell et al., 1979
Bicycle Ergometer	0-30 secs	Use LV & WT to Anthropometrically Predicted R	all out	Evans et al., 1981

output from a metabolic/sport specific aspect should help to elucidate the contribution of the ATP-PC system to short duration or impulse events as well as partial contribution in longer events. Thus, total or mean maximal power output should demonstrate the utilization of both the ATP-PC system and anaerobic glycolysis and any measurable decrements in mechanical power output would suggest corresponding metabolic inadequacies. Green et al. (1975) support the notion that it is possible to equate anaerobic energy time course and event time for the purpose of establishing training suitability or athletic weakness as measured by anaerobic power tests. Withers (1978) examined anaerobic power by means of a stair run and a 40-60 second treadmill run and compared venous blood lactate measurements. As would be expected lactates were high. The measurement of blood lactate, by many investigators (Campbell et al., 1979; Costill et al., 1976; Saltin et al., 1971; Withers et al., 1979; McGrail et al., 1978) has shown undoubtedly that anaerobic sources of energy are being used in these anaerobic power tests and some researchers (Gollnick et al., 1972; Gollnick et al., 1973) have taken muscle biopsies to establish the relationship between blood and muscle lactic acid level as well as levels of anaerobic substrates.

Other methods utilized to examine anaerobic power are oxygen (O_2) debt/deficit, phosphagen, creatinephosphokinase (CPK) and phosphofructokinase (PFK) levels and other significant substrates and enzymes. Most recently anaerobic power has been examined in relation to these parameters so that the time course for anaerobic metabolism can be established in relation to physiological performance (Katch et al., 1977; Costill et al., 1976).

Equipment most recently used for testing anaerobic power is the Cybex isokinetic machine. Research is limited but a relationship

between this apparatus and better known anaerobic power tests seems to exist.

Anaerobic Power in Female Athletes

Studies on anaerobic power for the female athlete are not abundant and even though the muscle fiber size is smaller in females than males they are able to perform anaerobic work quite successfully (Costill et al., 1976). The measurement of such performance in females has been examined by Withers (1978), Withers et al. (1979), Bar-Or et al. (1977), Campbell et al. (1979), De Bruyn-Prevost et al. (1980), Dotan et al. (1980), Kidner (1974) and Ready (1977).

Bar-Or et al. (1980) showed that at approximately 12 years of age, females performed similarly to males both for peak and mean power output on a 30 second all out ergometer test. By the adolescent years, differences were beginning to appear between males and females (Inbar et al., 1976) and comparison of power output for twenty year old males and females showed a mean difference of 36%, the males being superior (Withers et al., 1979).

Comparison of research on anaerobic power in females (Kidner, 1974; Ready, 1977) with male data has shown differences of 15-30%. Withers (1978) in his analysis of anaerobic power using the Margaria stair run and 40-60 seconds maximal treadmill run also demonstrated that females have significantly lower anaerobic power than males.

This sex difference may be attributed to the smaller muscle cross-section found by Costill et al. (1976) even though enzymatic profiles were no different. It appears that greater muscle bulk will mean a greater enzymatic pool, more muscle fibers and hence more mechanical work done. The fact that males have a larger cross-sectional area with

the same enzymatic profile as the females does not indicate, on a fiber count per unit area basis, whether there are male/female differences.

Cumming (1973) examined two indices of anaerobic power and associated blood lactate in males and females aged 12-17 years and demonstrated lower anaerobic power values in the females despite no significantly different results in serum lactates. Knowlton et al. (1980) further substantiated this female/male difference in anaerobic performance; again on the Margaria stair run (76.6 $kgm.sec^{-1}$ and 106.6 $kgm.sec^{-1}$ respectively). The analysis of National level orienteers and middle/long distance runners showed that anaerobic power output in endurance athletes was considerably lower than anaerobically trained athletes (Knowlton et al., 1980; Taunton et al., 1980). A definite gap in the literature exists when comparing anaerobic power output in females for different types of anaerobic activities.

CONTRIBUTING ENERGY SYSTEMS

The energy requirements for muscular contraction can be supplied by three possible mechanisms. These sources of energy are time and intensity dependent and this dependency may be a key factor in maximal utilization. At the onset of high intensity work, energy is supplied by immediate sources (ATP-PC system) which can sustain exercise for up to 5 seconds with anaerobic glycolysis (a short-term source possibly lasting up to 3 minutes indicates Astrand et al., 1977) then maintaining the exercise until aerobic or long term sources assume major responsibility for supplying energy (Edington and Edgerton, 1976). The utilization of immediate and short term energy sources evolves as a result of the 'lag' period when aerobic mechanisms are unable to supply the required energy for body functions in an exercise state (Hermansen,

1969). The supply of such energy sources is limited but available for short duration, high intensity muscular work. This 'lag' period during the early stages of supramaximal exercise is physiologically accounted for by adjustment of both the respiratory and circulatory system to increased ATP demands for cross-bridge cycling and thus muscular contractions (Mathews and Fox, 1976).

Availability and Hydrolysis of ATP-PC

The immediate (0-5 secs) energy systems that an individual would utilize for supramaximal exercise such as an 'all'out' 30 second anaerobic power test would be the splitting of phophocreatine to form ATP. The abundance of PC is triple that of ATP (Margaria, 1976). Creatine phosphokinase is the enzyme responsible for the production of ATP via this chemical cleavage and is found throughout the muscle in close proximity to the contractile filaments. ATP will continue to be formed until the muscle is exhausted of its phosphagen supply (Gollnick et al., 1973).

The other one-enzyme reaction that occurs to produce ATP is myokinase (MK) catalyzed reaction of two ADP molecules converted to ATP and AMP (Edington et al., 1976). It is the increase in AMP molecules that acts as a stimulus to the short term sources of energy. In fact, AMP aids in the initiation of glycogenolysis and glycolysis by activating phosphorylase-a. Glycogen is broken down to glucose-1-phosphate by phosphofructokinase (the rate limiting enzyme involved in mobilization of the glycolytic pathway). The activation of these enzymes leads to the mobilization of the next most immediate source of energy: non-oxidative sources. Hydrolysis of ATP-PC maintains energy for contractile purposes for only the first few seconds of activity (Wenger and Reed, 1976; Edington and

Edgerton, 1976).

Anaerobic Glycolysis

Stimulated by an increase in AMP and intensity of work (Karlsson and Saltin, 1970), carbohydrates are metabolized in an extensive series of reactions known as glycolysis. In fact at intensities of 150% $\dot{V}O_2max$ the rate of glycogen metabolism can be 10 $mM.kg^{-1}$ wet muscle mass.$minute^{-1}$ (Saltin and Karlsson, 1971). Taunton et al. (1980) confirm that 30 second anaerobic power tests at such supramaximal intensities do test glycolytic power of the system. Stored glycogen in the muscle is broken down to glucose-6-phosphate (G-6-P) and then via a series of non-oxidative reactions forms lactate as one of its by-products. A much larger quantity of ATP is formed and consequent activity can be maintained from 30 seconds to 2 minutes. The other by-products, alanine and Acetyl CoA, have their separate functions; the former is re-formed to glucose in the liver (gluconeogenesis) and the latter is the link to oxidative or aerobic metabolism (long term energy sources).

The by-products of anaerobic glycolysis are very acidic in nature and exercise limiting at intensities exceeding 90% $\dot{V}O_2max$ (Saltin and Karlsson, 1971). The production of lactate, in particular, has been shown to have an approximate linear relationship to the intensity of supramaximal exercise (Margaria, Ceretelli, Di Prampero, Massari and Torrelli, 1963) despite the level of glycogen depletion (Saltin and Karlsson, 1971).

The utilization of these anaerobic energy sources at the onset of exercise, which lasts anywhere from 20-30 seconds or 2-3 minutes (Katch et al., 1977) must not be confused with the anaerobic mechanisms that come into play at workloads usually above 40% $\dot{V}O_2max$. Substrate

utilization is predominantly CP and stored glycogen, however, it must be noted that this does not presuppose that only lactate, as a by-product, will be formed as opposed to alanine or Acetyl CoA.

Transfer to oxidative processes coincides with the vascular system supplying oxygen to the working muscles. Thus fatty acids and the by-product of anaerobic glycolysis, Acetyl CoA, are oxidized in the citric acid cycle. At this point exercise will be largely aerobic. Katch et al. (1977) have shown in fact that with all-out pedalling at supramaximal levels aerobic mechanisms contribute only 13% of energy after 20 seconds of work and approximately 19% at 40 seconds of exercise if O_2 deficit/debt data is examined. This finding suggests that for a 30 second test approximately 84% of energy will be derived from the summative supplies of ATP from phosphagen splitting and anaerobic glycolysis. Evans and Quinney (1981) suggested the first 5 seconds of their 30 second anaerobic power test reflected phosphagen splitting rate and the total power output reflects both phosphagen and glycolytic sources (predominantly anaerobic).

That the ATP-PC system is the initial energy source is confirmed in studies by Hultman, Bergstrom, McLennan and Anderson (1967). Even when CP levels are depleted ATP concentration is 60-70% higher than that measured at rest (Gollnick and Hermansen, 1973). Increased AMP concentration stimulates anaerobic glycolysis and results in lactate which can be both a physiologically and a psychologically limiting factor in exercise. High lactic acid levels have been shown to parallel the subject's perception of fatigue (Karlsson and Saltin, 1971). This study involved 5 successive, supramaximal, one minute efforts producing depletion of glycogen, G-6-P, ATP, CP and ADP, and increases in blood lactate and oxygen deficit.

Anaerobic capacity has been found to be very dependent on density of FT (fast twitch) fibers and Tesch (1978) found a relationship between % FT fibers and lactate concentration in exercise of 120% $\dot{V}O_2$max ($r = 0.85$). Factors which appeared to produce fatigue in working muscle were reduced PFK activity due to increased acidity and decreased AMP concentration. It was suggested muscle membrane permeability for Na^+ alters the muscle action potential and H^+ and Ca_2^+ compete for binding sites on actomyosin. Muscle fatigue due to decreased glycolytic and phosphorylitic energy production is caused by depletion of glycogen, delay in phosphorylase b activation, reduced hydrogen ion acceptor NAD^+ in the cytoplasm and decreased inorganic phosphate in muscle fibers (Wenger and Reed, 1976).

From a functional rather than cellular perspective, the reduced capacity for lactate to be diffused to other body compartments and active metabolism of lactate may detrimentally effect performance (Astrand, 1976). More recently, it has been shown that CPK levels may have some rate limiting effects on lactate production. For these reasons lactate can only be indicative of the extent of anaerobic processes and not a quantitative analysis of what is actually happening at the cellular level.

Oxygen Debt/Deficit

The 'lag' period during the early stages of supramaximal exercise or exercise above 50% $\dot{V}O_2$max, as previously stated, is the time taken for respiratory and circulatory systems to adjust so that the more efficient aerobic energy mechanisms are utilized. This lag is often referred to as the oxygen deficit.

At the cessation of exercise any oxygen utilized in excess of basal

levels is known as the oxygen debt because restoration of metabolites is taking place.

Factors which predominantly contribute to this delay are the replenishment of oxygen and regeneration of phosphagen stores. The post-exercise state of increased cardio-pulmonary function, increased hormonal and enzymatic concentrations and increased body temperature also hinder the return to basal metabolism (Knuttgen, 1969).

When Withers (1978) examined Australian Lacrosse players on the Margaria stair run and an all-out treadmill run to exhaustion (40-60 secs) he identified the existence of an alactacid and lactacid power measurement for the respective tests.

The alactacid debt is associated with restoration of all metabolites of exercise except lactic acid (up to 4 liters of oxygen or more depending on length of exercise) and is usually quite quick. It is lactacid oxygen debt that takes a more prolonged period for repayment and corresponds largely to resynthesis of lactate (Knuttgen and Saltin, 1973). Lactate must be oxidized to be resynthesized.

Time course for repayment of alactacid and lactacid debt as estimates of anaerobic energy stores however should not be used since studies indicate poor relationship between these parameters (Katch and Henry, 1972; Graham and Andrew, 1973). Roberts and Morton (1978) found only the alactacid portion to correlate significantly with oxygen uptake at the end of exercise ($r = 0.89$). The lactacid contribution appeared to indicate or correspond to anaerobic power and capacity and this showed in increased debt over oxygen deficit due to elevated anaerobic involvement.

FACTORS INFLUENCING OPTIMAL USAGE OF ANAEROBIC ENERGY

It must be remembered in any evaluation of physiological performance that many intervening factors must be considered or acknowledged in their interpretation.

Substrate Availability

Substrate availability can be influenced by factors such as diet, drugs, prior exercise, training protocol and training status. Prior exercise of a suitably intense nature, will deplete phosphagen and glycogen stores causing any succeeding supramaximal work bouts to be poor indicators of an individual's anaerobic power. Training as it relates to substrate availability is very important in determining one's capabilities as an anaerobic athlete and shall be dealt with shortly. The excessive use of anabolic steroids or insufficient diet also detrimentally effect substrate availability and hence anaerobic work capacity. Anaerobic performance largely depends on the levels of ATP-PC and glycogen in the muscle since free fatty acids (FFA) are metabolized only in the presence of oxygen. Also, increased blood lactate concentration inhibits the mobilization of FFA (Astrand and Rodahl, 1977).

Environmental/Extraneous Variables

1. Experimental Conditions. For aerobic exercise an optimal temperature of 19-20°C was maintained (Astrand et al., 1976). No such relationship appeared to exist for anaerobic exercise. Bar-Or, Dotan and Inbar (1977) utilized the 30 second power output test to determine effects of combinations of heat and humidity on 10 to 12 year old males and females exposed to experimental conditions for 45 minutes. No significant differences were found in mean performances and they concluded success was independent of short exposures to different climates.

Dotan and Bar-Or (1980) also examined climatic heat stress and found anaerobic performance not to be detrimentally effected by heat or humidity. When muscle temperature was lowered, Asmussen et al. (1976) found decreased performance in the Sargent jump. Anaerobic performances are not detrimentally affected by altitude and in fact may be enhanced (Mathews and Fox, 1976).

A two hour post-absorbtive state has been suggested prior to the supramaximal test as well as abstainence from exercise (Evans and Quinney, 1981; De Bruyn-Prevost et al., 1980; Katch et al., 1977; Astrand and Rodahl, 1977).

2. Age. Anaerobic power appears to peak at approximately the 20-30 year age bracket and values of 1.5-1.6 $kgm.kg^{-1}.sec^{-1}$ have been recorded. By the age of seventy, anaerobic power has declined by half (Margaria et al., 1966).

3. Sex. In their measurement of maximum anaerobic alactacid power in males and females Withers, McFarland, Cousins and Gore (1979) found males to be superior to females by 58.97 kgm/sec for the Margaria stair climb. Comparison of 15 year old males and females in their development of anaerobic power on the 30 second bicycle ergometer test showed males to be superior by 144.8 watts. Serum lactates of subjects in this study were similar (Cumming, 1973).

Devries (1974) suggested the musculoskeletal system of females to be less well adapted to such activities and the research of Costill et al. (1976) supported this concept. Costill et al. (1976) found fiber area to be less in elite female track and field athletes. However, fiber composition and enzyme activity were similar to their male counterparts. Comparison of power outputs in terms of lean body weight (LBW) for males and females could not be located.

4. Perceived Exertion. High intensity, short duration exercise which involves the utilization of phosphocreatine and anaerobic glycolysis consequentially results in the production of LA. The accummulation of LA varies widely in particular types of athletes (Taunton et al., 1980; Bar-Or et al., 1978; Gollnick et al., 1973). However, one must undoubtedly question the adverse effects such build up will have on performance (whether these be physiological or psychological in nature) in a 30 second anaerobic power test as seems to be the case in $\dot{V}O_2$max and other such tests measuring physiological capacities (Pandolf, 1978).

Is a person's ability to perform supramaximally for 30 seconds detrimentally effected by the build up of metabolites such as LA? It has been shown that a positive relationship ($r = 0.64$) exists between rate of perceived exertion and blood lactate (Allen and Pandolf, 1977; Ekblom and Goldbarg, 1971) and may effect an individual's tolerance to exercise. The case for lactate and/or local factors effecting perceived exertion does however seem doubtful when the works of Stamford and Noble (1974) are examined. Sargeant et al. (1973) also found no correlation but suggested $\dot{V}e$, $\dot{V}O_2$, HR and relative aerobic stress to be more indicative of perceived exertion. The controversy between peripheral or central mechanisms seems to be explained best by Ekblom and Goldbarg (1971) who suggest that when small muscle groups are involved, peripheral mechanisms seem to stimulate the perception of exhaustion whereas when large muscle groups are utilized, an additional stress is involved and central mechanisms further amplify the rate of perceived exertion. The implications are that metabolic functioning (namely, aerobic or anaerobic) may be a factor that alters the extent to which peripheral or central mechanisms influence capacity for maximal exertion (Pandolf, 1978). It certainly does appear, from the studies cited, that cognitive

cues do exist in determining perceived exertion.

Most of the studies reviewed examined $\dot{V}O_2$max and % $\dot{V}O_2$max criterion to establish levels of perceived exertion. Studies specifically examining short duration high intensity exercise and performance in relation to perceived exertion could not be found but Lollgen et al. (1980) in their study of pedal frequency, force and muscle metabolites and effects on perceived exertion indicate that with maximal exercise (100% $\dot{V}O_2$max) at 100 revolutions per minute (RPM) there was a significant decrease in glycogen concentration. ATP and PC concentrations were also significantly depleted. However, when a low pedal rate and high resistance was involved the depletion of these systems was greatest. The implications from this data, for an individual performing at an optimal resistance with an all-out pedal rate, is that stored energy will be used optimally to produce work (Lollgen et al., 1980).

Lollgen et al. (1980) noted that muscle and blood lactates were significantly related to exercise intensity however neither blood lactic acid levels nor ATP-PC levels were indicative of rated perceived exertion.

Thus for a supramaximal effort of very short duration it would appear that neither peripheral nor central factors can be isolated as effecting performance of the task or perception of exhaustion (Lollgen, 1980). Performance on proceeding tests may, however, be detrimentally affected by one's perception of exertion as indicated by lactate accumulation and leg weakness at the completion of exercise. No evidence could be found to suggest that perceived exertion effects supramaximal tests even despite its distinctly anaerobic nature (Knuttgen, 1975). In the measurement of maximal power output perceived exertion during the exercise may be influenced by local mechanisms since only in the post exercise situation are central mechanisms experienced.

5. Training Status. It is evident that the energy sources, utilized at the onset of exercise and prior to aerobic mechanisms coming into play, are trainable. Withers (1978) showed marked increases in time for the treadmill run at the same absolute workload due to interval training as well as decreased time for the Margaria stair run.

Komi et al. (1977) found the difference between power athletes and distances to be 33 $kgm.sec^{-1}$. Blood lactates for endurance athletes were also found to be much lower. Taunton et al. (1980) also showed anaerobic power to be lower for middle and long distance runners as did Knowlton et al. (1980) for championship class orienteers. The research of Thomson and Garvie (1979) showed marathoners expended less anaerobic energy than sprinters and in fact marathoners showed decreased time for the aerobic system to kick in at the onset of exercise (Hagberg et al., 1978).

Campbell et al. (1979) showed improvement in performance of 20 females participating in a 6 week anaerobic training programme. Both Sargent jump and high resistance anaerobic power test results were significantly different pre- and post-training. Weltman et al. (1978) in their training study found aerobic, peak anaerobic and total anaerobic power to increase 10.5%, 13% and 12% respectively, with all-out pedalling twice daily at 4 kg resistance over a 6 week time period. Intensity appeared to be the key factor in their study.

Green and Houston (1975) found 4.7% improvement in anaerobic power in an elite junior ice hockey team for pre- and post-season tests. In other studies, training produced 16.7-23% increases in anaerobic capacity and 14-17% increases in blood lactate as measured from treadmill run protocol (Cunningham et al., 1969; Houston et al., 1977).

6. Genetic Influences. In a comprehensive study by Komi and

Karlson (1979) monozygous and dizygous twins were examined for differences in anthropometric measure, Margaria stair climb, maximum isometric leg force, EMG, aerobic power, peak lactate muscle fiber composition and enzyme activity. Heredity appeared to account for the relationship between muscular power and fiber type distribution. Genetic factors, it was suggested largely account for power differences in males.

7. Series Elastic Component. First coined by Levin and Wyman in 1927, they proposed that the elastic component that allows muscles to store energy could be expressed in terms of a parallel-elastic component and a series elastic component. The latter, of which there will be particular influence upon mechanical performance, is associated with the elastic properties of tendons intramuscular connective tissue and sarcolemma. The parallel elastic component is related to cross-bridging between myosin and actin filaments (Asmussen, Bonde-Peterson and Jorgensen, 1976; Huxley, 1974).

As evidenced by Komi (1980) in biomechanical analysis of racing, walking and long jumping, the series elastic component of exercise appears to be most prolific in the eccentric phase (negative work) exercise rather than concentric phase. Any increase in force and mechanical output was related to the value of the apparent spring constant of the support leg in the eccentric phase. As velocity of motion increased so too did the component attributed to elasticity of musculature and potential to store energy (Luhtanen et al., 1980). Komi suggested the combined elasticity of muscles, bones and tendons may be very indicative of mechanical performance.

Certainly the storage of elastic energy in the muscles occurs in the period when they are being stretched (Asmussen et al., 1976; Cavagna et al., 1971). In bicycle ergometry, at approximately the top

of the pedal phase, the vasti portion of the quadriceps muscle is at its optimal length (stretch) and approaching the contraction phase. Increases in mechanical power by increased load and maximal revolutions per minute may enhance performance in supramaximal bicycle ergometry as suggested by Asmussen et al. (1976). Controversially, however, Harrison (1970) suggested this was not the case. In fact, if the series elastic component of pedalling were absent, one would see a possible 18% increase in power output. The stiffness of the series elastic component, he suggested, increases with load. This increase, according to Asmussen et al. (1976), should enhance performance so evidence is not clear as to the influences of the series elastic component in bicycle ergometry. In reviewing individual performances and contribution of the series elastic component (more influential in the result and measurement of mechanical power than parallel elastic components) evidence seems equivocal as to its portent.

8. Anatomical Advantage. For the Margaria stair run Withers et al. (1979) have demonstrated that leg length does effect performance. To have relatively long legs enhances performance on this anaerobic test. For standardization in bicycle ergometry, the knee is required to be slightly bent at the vertical position of the pedals. This has been found to be most mechanically efficient regardless of limb length (Astrand et al., 1976; Nordeen-Snyder, 1977).

9. Force/Velocity Relationship. Hill (1922, 1938) showed a hyperbolic relationship between force and velocity in isolated muscle preparations. Since then Wilkie (1950) showed that if inertial factors were taken into consideration, human skeletal muscle in vivo demonstrated this same characteristic.

Sjogaard (1978) demonstrated this hyperbolic relationship by determining speed and force for 4-5 revolution outputs and at 70-100% of $\dot{V}O_2$ max but the force/velocity curves also varied according to optimal loading and speed (Seabury et al., 1977). It is evident that optimal force/velocity relationships exist for each muscle and differ between individuals (Komi, 1973) according to fiber type (Sjogaard, 1978). For example, peak force/pedal thrust decreased with increasing pedal frequency (Sjogaard, 1978) and isokinetic exercises at low speed were more indicative of FT fibers being recruited than at fast or zero speed conditions (Gregor et al., 1979).

It is to be noted that the force/velocity and power/velocity curves change markedly when stored elastic energy in muscles is used (Cavagna et al., 1971). In fact, Cavagna (1977) showed the efficiencies (mechanical) of bicycling to be .260 compared to .391 for running (i.e., 26% and 39.1%). He suggested that running is more suitable to utilization of stored energy from the negative work phase than bicycling. Asmussen et al. (1974) support these findings. Loaded cycling resulted in 25.1% efficiency.

10. Body Composition. Studies (Kitagawa et al., 1980; Caiozzo et al., 1980) have shown obesity or external load to be advantageous in the Margaria stair run; both time to complete the task and total power output were increased. This effect of excess weight, however, does not hold true for ergometry since it is weight supported. Rather, weight due to muscle mass utilized appears to be the key factor in determining anaerobic performance (Davies, 1971).

Conflicting evidence is provided by Katch (1974) who showed body weight to account for 41% of variance in total power output between individuals and leg volume to be 36% of the variance especially in

intensive exercise. A later study (Katch et al., 1977) showed lean body mass to be a better correlate of total work done.

Muscular Components

Several factors may influence the results of any anaerobic testing. These factors include the fiber composition of the athlete, effects of neural control on performance, arrangement of fibers and angle/length ratios.

Muscular arrangement is very important since it determines the force/velocity relationship of that particular muscle (Josephson, 1971). Maximal force is directly related to the cross-sectional area of the muscle, however, whether these fibers are largely slow or fast twitch is going to have a significant bearing on force production. FT fibers are known to be cross-sectionally larger and thus may occupy a larger area even though percentage-wise this may not be apparent (Saltin, 1973; Edgerton, 1976). Cross-sectional area is also dependent upon whether the muscle fibers are in parallel or in series; parallel arrangement would obviously display a larger cross-section than in series. The effects % FT fiber type has on power output is to influence glycolytic capacities of the overall muscle and hence anaerobic performance.

Arrangement (i.e., fusiform or pennate) effects the force/velocity relationship of a muscle (Shephard, 1972). Fusiform muscles produce work via speed of movement whereas pennate fibers largely produce work via the work exerted. Consequently the product of force and velocity under particular circumstances may exhibit similar capabilities for producing work even though the major contributing components (force of contraction vs. speed of contraction) may be vastly different (Josephson, 1975). Muscle arrangement is often associated with limb length and

function. If power is required, then there is a pennate arrangement of fibers; conversely speed fibers are fusiform.

In examination of anaerobic capacities and predominantly anaerobic athletes, Komi et al. (1977) exemplify the apparent relationship between fiber type and anaerobic capacity. For the Wingate protocol and runs of various distances Inbar et al. (1979) showed peak power and % FT ($r = 0.78$) to be good predictors of 40 meter sprint performance whilst total power output and peak power output were better for 300 meter performances ($r = 0.72$). Campbell et al. (1979) found, in examination of fiber type, that performance could not be predicted.

Training, it has been observed, can alter fiber area (Saltin, 1973). Anaerobically trained athletes display FT fibers larger in size when compared to endurance trained athletes and males show a larger FT fiber size than females (Gregor et al., 1979; Costill et al., 1973).

Recruitment of fibers and thus dissipation of metabolites of anaerobic glycolysis are also important in determining anaerobic capacity (Anderson et al., 1975). Slow twitch oxidative fibers may contribute to lactate removal whilst showing no signs of depletion of their own glycogen stores.

The optimal force/velocity relationship needs to be found in all muscular activity to elicit an optimal response. Asmussen (1979) suggests the limits to intensity of exercise (power) and the amount of exercise (work) an individual can sustain are not necessarily attributable to the inability of muscles to maintain or develop a certain expected force or power. Rather, both central and peripheral mechanisms (neural and muscular) may result in impairment of activity. In other words whilst measurement of muscle function in terms of power output or force elicited may be beneficial, any impairment in performance may not

necessarily be due to inability of the muscles to maintain activity. Neural factors (e.g., transmission mechanisms) may be the controlling factor. Knuttgen (1975) supports this theory that there are neural limits to the muscle's ability for endurance in repeated movements. Thorstensson and Karlsson (1976) suggest inability to supply ATP and inability of coupling to take place in FT fibers may be associated with the motor neuron and the so called fatiguability of the muscle. They found a relationship between % FT fibers and leg fatiguability. Both force and velocity of contraction were greater in FT than ST fibers.

Warm-up For Supramaximal Exercise

The effects of warm-up on short maximal anaerobic exercise leading to exhaustion in one minute or less has not been extensively examined by researchers. De Bruyn-Prevost and Lefebvre (1980) examined five minutes of warm-up at 30% $\dot{V}O_2$ and 75% $\dot{V}O_2$max prior to the onset of exercise and found that warm-up at 30% enhanced performance whereas 75% was detrimental. Warm-up did raise heart rate and oxygen consumption slightly during the criterion exercise as compared to values for no warm-up but lead to no increase in lactic acid level. With a rest period between warming up and exercise, performance was not enhanced regardless of warm-up intensity. Physiological measurement changes of consequence were not found. With the 5 minute, 30% $\dot{V}O_2$max warm-up, the time to reach the criterion pedal frequency (females = 104-108 RPM and males = 124-128 RPM) was reduced whereas 75% $\dot{V}O_2$max increased that period. Lactates at the end of all conditions did not vary significantly. The conclusions from this study show that performance on the bicycle ergometer is significantly better and the anaerobic endurance capacity is enhanced when a 5 minute 30% $\dot{V}O_2$max warm-up takes place prior to

exercise. Differences in oxygen debt, in this study, were non-significant. Investigations (Watt and Hodgson, 1975; Gutin et al., 1976) of the effects of warm-up or no warm-up in exercises leading to exhaustion in one minute, two minutes and 90 seconds found heart rate and oxygen consumption to be elevated. Intensity was not examined however. Watt et al., (1975) also reported increased muscle and core temperatures as well as cardio-pulmonary adjustments and reduced frequency of ischemic response.

Bar-Or (1977) examined 10 minutes of intermittent warm-up (30 seconds exercise/30 seconds rest) in young adults and children and suggested heart rate criterion to reach 150 beats per minute and 160 beats per minute, respectively. Inbar and Bar-Or (1975) found power output for supramaximal bicycle exercise to be enhanced by warming up for 15 minutes (intermittent running and rest at 60% $\dot{V}O_2$max) preceding the criterion test.

Asmussen et al. (1976) showed that in vertical jumping (similar to vertical jump of Sargent [1921]) if the muscle temperature were increased, so too was vertical jump.

Metabolite Build-up

In Sahlin's extensive studies (1978), on dynamic exercise, blood lactates/pyruvates were found to be approximately equivalent to those found in the muscle due to the increased flow to the working muscle (in comparison to isometric type exercise). It is evident from this study that venous lactate and pyruvate is a legitimate means of assessing local fatigue, anaerobic capacity and the possible detrimental effects that it may have on function (i.e., decreased pH and accumulation of lactic acid and pyruvic acid at intensities above 60% $\dot{V}O_2$max). For subjects working

at/or in excess of their $\dot{V}O_2max$, the muscle approaches a saturation level for lactic acid/pyruvic acid (LA/PA) and so too should venous blood lactate provided the exercise is suitably intense.

Jorfeldt et al. (1978) demonstrated that in fact only during high intensity exercise does blood lactate not display a linear relationship with muscle lactate levels. Their findings stressed that with performances of greater than 87% $\dot{V}O_2$ this linearity no longer existed and in fact an asymptotic relationship came into effect.

To support this evidence, Sacks and Sacks (1937) found, from studies on cats, that at very high intensities of work a "storing" of lactate occurred within the tissue and was related to the most efficient buffer system for acids which are located intracellularly rather than extracellularly. Jorfeldt et al. (1978) state that there are translocation hinderances for lactate within the exercising muscle at higher intensities of exercise. They concluded that lactate formed in the muscle during exercise is released at low and moderate workloads but partly accumulated in the tissue at heavy workloads when the rate of lactate formation is high. Their data indicated a maximal capacity for lactate release corresponding to about 5 mmol/min using a series of needle biopsies from the vastis lateralis muscle and catheterization of the femoral artery and femoral vein.

MEASUREMENT OF ANAEROBIC POWER

Anaerobic power has been measured by a variety of methods. The usefulness of these tests as a measurement tool in exercise physiology can only be evaluated in relation to actual performances. Of particular interest is the relationship of the 30 second bicycle ergometer test to actual performances.

Bar-Or et al. (1977) showed correlations with the 300 meter and 25 meter swim to be 0.85 and 0.87 respectively and concluded a 30 second anaerobic power test on the bicycle ergometer to be an indicator of anaerobic capacity. Taunton et al. (1980), in their study involving endurance rather than anerobically trained athletes, found a poor relationship to exist between the Margaria stair run and peak anaerobic power elicited on the bicycle ergometer. This, however, is explained by Caiozzo et al. (1980) in that the Margaria stair run does not tax anaerobic stores or allow man to produce maximal work and only by giving a subject an external load to carry is it optimally taxed. In bicycle ergometry external load can be altered to obtain the optimal force/velocity relationship for the subject (Luhtanen and Komi, 1980; Caiozzo et al., 1980). Subjects must be optimally loaded in order to produce maximal power output or work (Harrison, 1970).

CHAPTER III

METHODOLOGY

EXPERIMENTAL DESIGN

This study was specifically designed to examine data compiled from multi-trial performances by individuals on the Wingate bicycle ergometer protocol, modified Wingate protocol and absolute resistance settings. In particular the following variables and their relationship to training status and activity were examined in this study:

1. Maximal power output (MPO)
2. Peak power output (PPO)
3. Energy sources utilized
4. Venous blood lactate levels
5. Ability to sustain exercise proportionate to maximal power output

To this end, the relationship of anthropometric measures (body weight [kg], leg circumference [cm], selected skinfolds [mm] and leg volume [liters]) to the force required to elicit maximal power output was examined with the intent of predicting the force to elicit PPO and MPO in single trial testing. This necessitated multiple trial tests of multiple trial tests including 3.5 kp and 4.0 kp absolute resistances for all subjects. The intratester reliabilities for venous blood lactates, leg volumes, circumferences and skinfolds had been established (see appendices H and C).

SUBJECTS

Twenty-eight active to highly trained female volunteers aged 17 to 27 years were recruited to participate in the study. Selection was based

on the type and level of both aerobic and anaerobic activity and training. All subjects were screened by completion of a Par-Q questionnaire (see Appendix I-II) and measurement of resting blood pressure and were required to complete an informed consent form (see Appendix I-I).

EXPERIMENTAL PROCEDURES AND EQUIPMENT

Body Density: Total body fat was estimated by using the formula of Brozek et al. (1963). Body density was determined by hydrostatic weighing as described by McNab and Quinney (1981). Vital capacity was measured with a Collins Vitalograph and the underwater weighing was completed with full inspiration. Chart readings for a minimum of three consistant underwater weighings were taken and the mean of the three readings were recorded.

Consent Forms, Par-Q Questionnaires, Resting Blood Pressure Tests and Training/Activity Status: All subjects were required to complete informed consent forms, Par-Q forms, and have resting blood pressures measured for the purpose of screening. A blood pressure of 150/100 mm Hg was considered unsuitable. A training/activity profile was completed and all subjects were expected to be training or involved in strenuous activity at least three times per week.

Leg Volume: Subjects suspended the right or dominant leg (one subject) vertically in water in a calibrated (to 0.1 liter) volume tank. The leg was immersed to the point at which the grasilis muscle attaches to the symphysis pubis but not beyond the gluteal furrow. The tank was filled to the top with the leg immersed as indicated. The subject was then required to remove her leg and the drop in water level or water displacement was indicative of her leg volume. Water temperature was maintained at 24° C throughout the testing

period.

Skinfolds, Circumferences and Body Weight: Circumferences of the thigh was taken horizontally 1 cm below the gluteal furrow of the right or dominant leg with weight evenly distributed. The calf circumference was taken at the point of greatest circumference (Ross, 1981). The calf skinfold was taken at the midline and medially at the point of greatest circumference. The thigh skinfold was taken at the anterior midline of the thigh, level with the point at which circumference was taken. Vertical skinfolds were taken and both were taken with the leg unweighted as described by Ross (1981). Circumferences were measured by using a steel anthropometric measuring tape. Skinfolds were measured by use of John Bull (British Indicators Ltd.) skinfold calipers and all weights were measured on a clinical balance (see Appendix C-V).

The Anaerobic Power Tests: Approximately six to eight 30 second anaerobic power tests were undertaken by all subjects. The subjects were firstly familiarized with the bicycle, the warm-up phase and the test itself. Modifications to the ergometer included installation of racing-style handlebars, toe clips and the mounting of dual microswitches on the cranks to count pedal revolutions. A modified Sanborn 100 ECG recorder was utilized for the purpose of permanently recording revolutions.

The seat height was adjusted so that only slight flexion of the knee existed at the down position of the pedal and the seat height recorded to standardize future tests. The ergometer was calibrated prior to every test using a static weight calibration procedure (McNab and Quinney, 1981). After warming up for two minutes at a resistance one-quarter to one-third of that required

for the actual test and approximately 60-80 rpm (revolutions per minute), the subject was required to pedal maximally for thirty seconds.

To maximize performance, at approximately 3-5 seconds prior to the onset of the 30 second test the subject began increasing pedal rate so that when instructed to 'go' (at the beginning of the 30 second test when the resistance had been quickly set) the subject was pedalling maximally. Strong verbal encouragement and feedback on time elapsed were given to encourage maximal performance. Revolutions were recorded for the whole 30 second period. To aid in recovery, a warm-down of approximately 0.5 kp for 2-4 minutes followed each test. A minimum time lapse of 20 minutes between paired tests was given and no more than two tests were performed on any one day (Evans et al., 1981; Bonen et al., 1979).

The resistance setting for each of the ergometer tests were as follows:

1) Absolute resistances of 3.5 kp and 4.0 kp
2) Wingate protocol or bracketing: a weight-relative resistance setting determined by multiplying the subject's weight by a factor of 0.075.
3) Resistances (approximately 3 to 5) "homing in" on the force to elicit peak power output.

The "homing in" of the R to elicit PPO took the form of stepwise 0.5 kp increments in resistance until the PPO was reached and any subsequent increase in increments showed a drop off in power output. Increments of 0.25 kp bracketing PPO were tested to substantiate that in fact PPO had been reached. A re-test of PPO then took place.

Analysis of RPM for each 5 second period of the 30 second test produced power outputs both in absolute terms (watts) and relative terms (watts.kg^{-1}). Peak, mean and total power output for the 30 second period were also recorded.

Blood Sampling and Analysis: From the sample tested in this study one person was randomly selected from each of the 6 sub-groups to participate in time course analyses of power output versus blood lactate levels. Haematocrits were also examined to establish the relative effect of haemoconcentration on [LA]. All analyses utilized Sigma Lactic Acid analysis kits and all samples were analyzed within one month of collection.

Basal blood lactate levels were determined and then each of the subjects were required to have blood samples taken after the following randomized tests:

1) Blood lactate after 2 minutes warm-up.
2) Blood lactate after only 5 seconds of the 30 second test.
3) Blood lactate after only 15 seconds of the 30 second test.
4) Blood lactate after completing the 30 second test.

All samples were taken after 5 minutes of recovery with no recovery period as this allowed sufficient time for peak lactate diffusion levels to occur (Freund et al., 1980; Sahlin et al., 1976). Trained personnel took all blood samples as each subject was in a two hour minimum post-absorbtive state.

Experimental Protocol: The subjects were exposed to the following sequence of testing:

DAY ONE:

1) Consent forms, Par-Q, Training status and resting blood pressure.

2) Body density.

3) Anthropometric measures.

4) Orientation of equipment, procedures and recording of correct seat height.

5) Two of the 30 second bicycle ergometer tests.

DAY TWO:

1) 4.0 kp resistance.

2) 0.075 of body weight (kg) = R(kp).

DAY THREE AND FOUR:

1) Resistance homing in on PPO.

2) Resistance homing in on PPO[1].

Once PPO was established selected subjects were randomly tested for blood lactate response to the previously outlined protocols.

STATISTICAL ANALYSIS

Analyses involved a step-wise multiple regression to determine appropriate parameters to predict maximal power output and peak power output. The Michigan Interactive Data Analysis System (MIDAS) was used for this statistical analysis and the probability of the F ratio occurring by chance was examined at the 0.05 level. For anaerobically trained athletes a one-way ANOVA of differences between groups (anaerobic and aerobic) for both maximal and peak power output, and appropriate post-hoc tests were also utilized. Lactate concentrations and haematocrits were examined graphically.

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[1]A period of 24 hours elapsed between each day of testing.

CHAPTER IV

RESULTS

The physical and anthropometric characteristics of 28 experimental subjects, 24 anaerobically trained and 4 aerobically trained, were examined (Appendix: A-I to VII) and characteristics particularly pertinent to this study are summarized in Table II. The five anaerobically trained groups and one aerobically trained group respectively comprised of: (1) Basketball Athletes (n = 6), (2) Volleyball Athletes (n = 7), (3) Gymnastics Athletes (n = 5), (4) Cycling Athletes (n = 3), (5) Track and Field Athletes (n = 3) and (6) Endurance Athletes.

Mean results for the six groups on peak power output (PPO) at common force settings corresponding to 3.5 kp, 4.0 kp, the Wingate setting and the force to elicit actual PPO on the 30 second bicycle ergometer test are shown in Table III. Mean results for these six groups on mean maximal power output (MPO) at the four resistance settings cited can also be found in Table II.

To establish power outputs, both the actual peak power output and the actual MPO, subjects were required to complete between 7 and 12 separate tests on the bicycle ergometer. An example of the power/time relation for seven such trials executed by subject 106 (where 1 represents basketball and 06 subject number) is represented in Figure 1. Compilation of this data enabled examination of both peak power output for each trial and maximal power output for each trial. For this subject, the peak power output/force curve is represented in Figure 2 as well as the curve for maximal power output/force (see Appendix : B-I to VI for typical power curves for each experimental group).

In examination of force settings and power outputs for the anaerobic

TABLE II. Summary of Physical and Anthropometric Data for Each Experimental Group* (mean ± S.D.) (where ST, TC and CC represent weight, thigh circumference and calf circumference respectively)

GROUP	1	2	3	4	5	6
Age (years)	21.00 ± 2.56	18.52 ± 1.90	19.60 ± 1.14	23.67 ± 3.51	19.33 ± 3.21	23.50 ± 4.04
WT (kg)	62.94 ± 6.98	65.97 ± 5.52	53.04 ± 6.70	62.25 ± 9.42	63.57 ± 3.35	57.13 ± 5.13
TC (cm)	56.52 ± 3.17	58.16 ± 3.29	53.01 ± 4.26	57.27 ± 5.20	56.07 ± 1.89	53.92 ± 4.17
CC (cm)	35.32 ± 1.66	36.41 ± 1.59	33.70 ± 1.67	36.07 ± 3.37	35.28 ± 0.68	35.46 ± 2.18

*The group numbers used here and in future reference correspond as follows:

1 = Basketball, 2 = Volleyball, 3 = Gymnastics, 4 = Cycling, 5 = Track/Field, 6 = Aerobic

TABLE III. Mean Results for the Six Experimental Groups on Peak Power Output (PPO) and Maximal Power Output (MPO) at 3.5 kp, 4.0 kp, WIN(R), PPO(R) and MPO(R) Resistance Settings

GROUPS / PARAM.	1	2	3	4	5	6
PPO (3.5)	501.96 ±30.85	473.85 ±26.60	403.80 ±51.71	432.60 ±00.00	453.24 ±41.10	422.34 ±76.15
PPO (4.0)	569.00 ±34.62	521.54 ±27.38	433.89 ±97.75	468.92 ±26.51	286.60 ±49.03	482.67 ±49.01
PPO(WIN)	612.58 ±63.96	590.51 ±58.57	451.46 ±91.36	539.96 ±61.75	533.20 ±94.71	511.71 ±43.62
PPO	662.44 ±74.79	659.88 ±62.04	488.23 ±104.78	593.52 ±67.28	668.04 ±45.32	520.92 ±42.63
MPO (3.5)	429.68 ±24.62	403.20 ±09.49	337.85 ±45.66	376.56 ±20.14	366.28 ±44.75	369.75 ±61.69
MPO (4.0)	475.40 ±21.65	438.19 ±15.73	350.23 ±73.19	401.72 ±19.49	398.00 ±42.55	401.25 ±60.29
MPO(WIN)	489.84 ±39.22	463.16 ±24.74	362.83 ±54.83	432.60 ±24.68	446.52 ±59.55	445.59 ±63.24
MPO	518.58 ±47.12	501.27 ±34.39	382.68 ±64.04	458.76 ±44.89	497.60 ±34.52	446.10 ±63.18

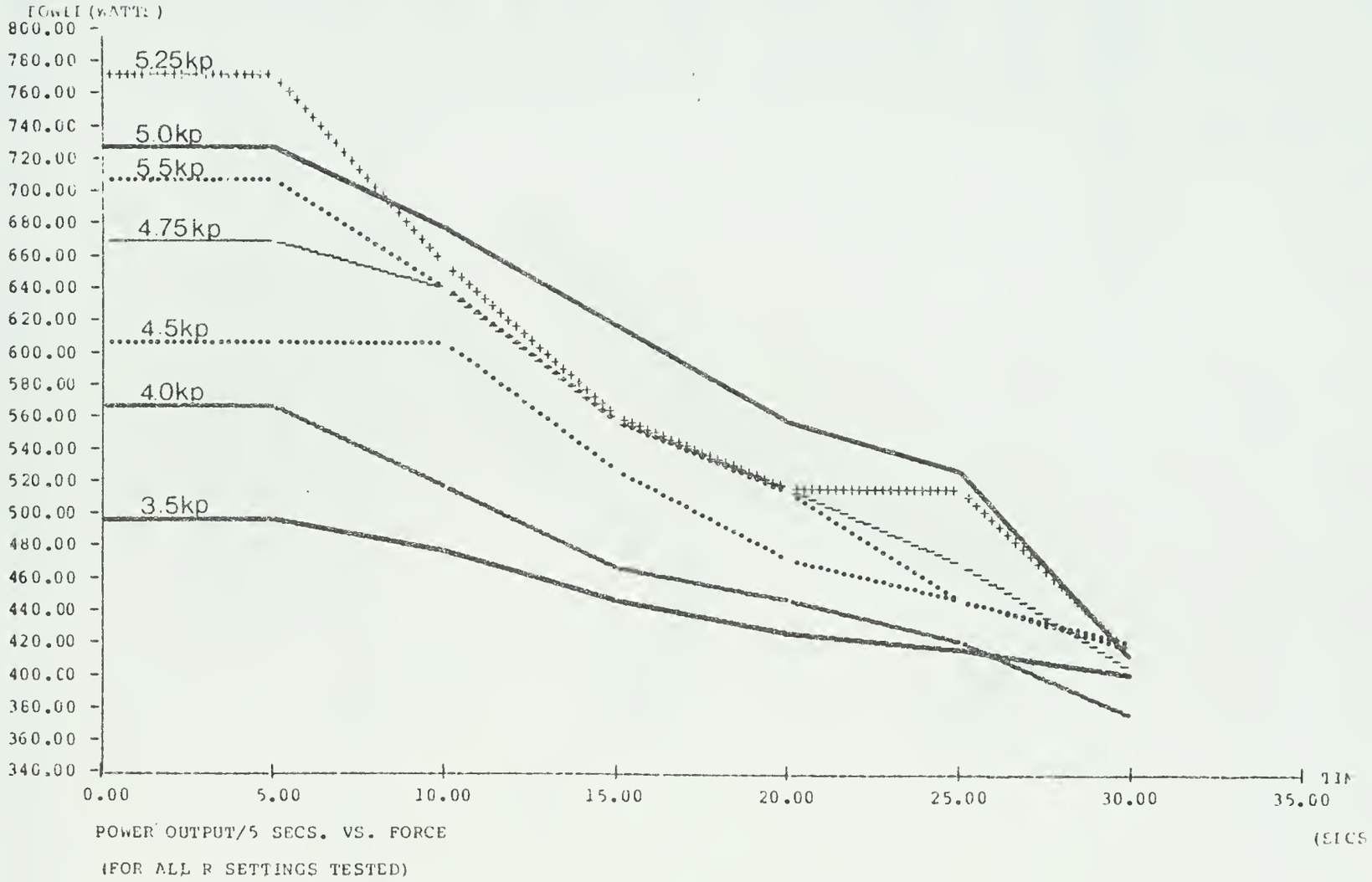


Figure 1. Power Output (Watts) Each 5 Seconds of the 30 Second Bicycle Test Vs. Time for Subject 106

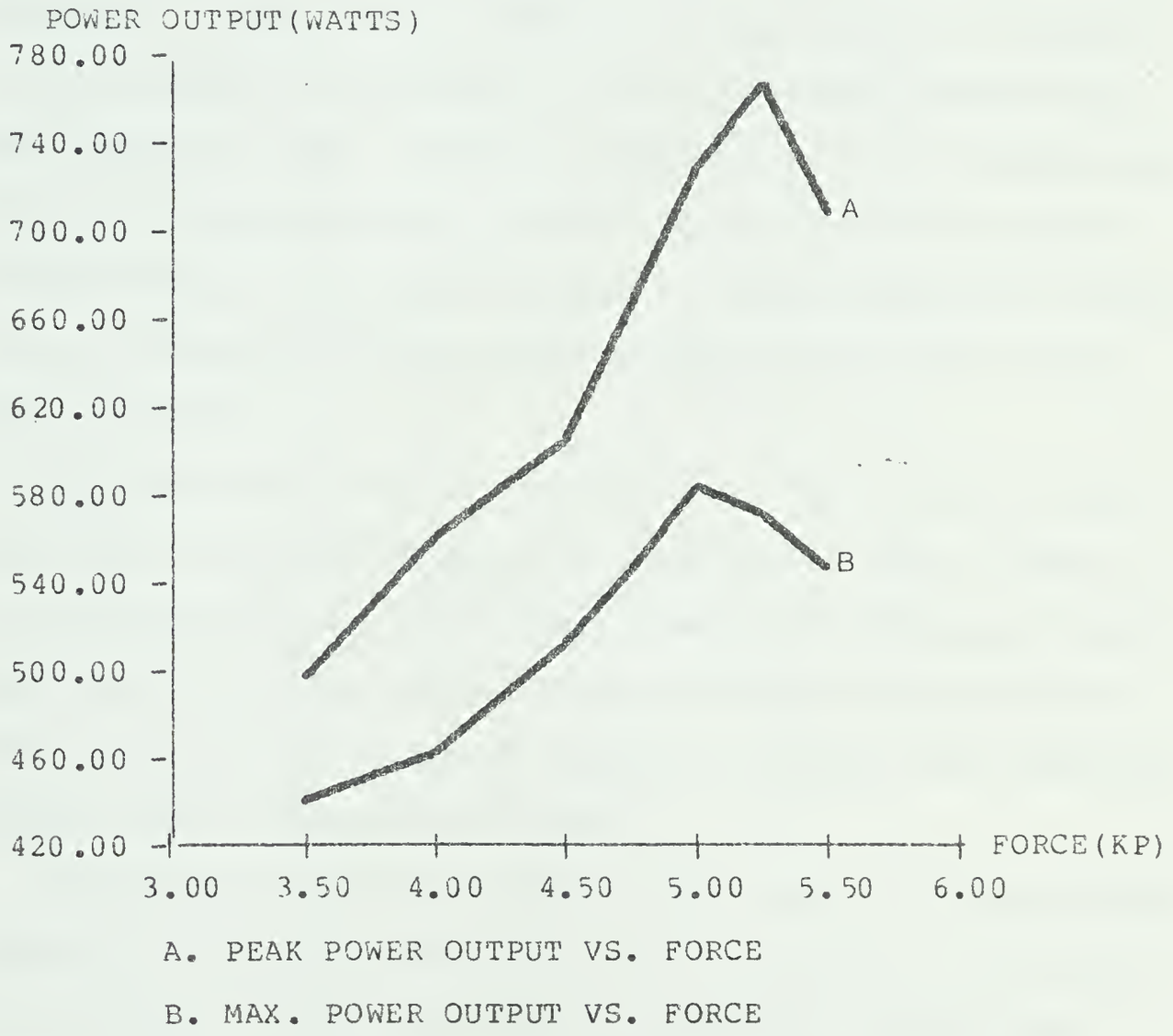


Figure 2. Peak Power Output Vs. Force Setting (A) and Maximal Power Output Vs. Force Setting (B) for Subject 106

group, a mean force of 5.06 ± 0.77 kp was required to elicit PPO, 5.10 ± .72 kp to elicit MPO, and 4.64 ± .57 kp the force predicted by the Wingate protocol. Significant differences between the Wingate force setting and both the forces required to elicit PPO and MPO were found ($\alpha = 0.05$). Power produced at these force settings produced PPO of 617.64 ± 98.52 watts (mean ± S.D.), MPO of 477.48 ± 68.04 watts, PPO(WIN) of 546.72 ± 88.32 watts and MPO(WIN) of 449.900 ± 71.88 watts. Again, significant differences in power were elicited by the Wingate protocol as compared to those measured in this study, the latter being more favourable for the production of power. In fact, a difference as large as 163.38 watts between the Wingate resistance and the force to elicit PPO was demonstrated by one of the basketball players. The mean velocity of pedalling to elicit PPO and MPO for the anaerobic group was 95.4 ± 13.1 RPM and 95.5 ± 11.97 RPM.

For comparison of power, in relative terms, the results of PPO/KG body weight and MPO/KG body weight for each group is shown in Table IV. It was observed that the aerobic group showed fewer differences in power production for 5 seconds compared to 30 seconds but with sports more prone to impulse activity such as basketball, volleyball and track/field markedly larger differences can be seen.

Reliabilities for peak and maximal power output for all experimental subjects (n = 28) on test-retest data are shown by pearson correlations of r = 0.95 and r = 0.98 respectively, significant at the 0.05 level (Appendix: C-I). Reliabilities for anthropometric data are as follows: (1) Leg Volume; r = 0.912.2, (2) Thigh Skinfold; r = 0.979, (3) Thigh Circumference; r = 0.989, (4) Calf Skinfold; r = 0.977, (5) Calf Circumference; r = 0.991 (significant at the 0.05 level, see Appendices C-II to IV).

TABLE IV. Peak Power Output and Maximal Power Output per Unit Body Weight for Experimental Group watts/kg ($\bar{X} \pm$ S.D.)

GROUP	1	2	3	4	5	6
PPO/KG	10.59 ± 1.27	10.01 ± 0.98	9.19 ± 1.64	9.62 ± 1.13	10.51 ± 0.36	9.19 ± 1.28
MPO/KG	8.25 ± 0.73	7.62 ± 0.53	7.22 ± 0.94	7.48 ± 1.26	7.83 ± 0.32	7.87 ± 1.37
$\bar{X}$ ± S.D. (diff.)	2.34 ± 0.55	2.39 ± 0.63	1.97 ± 0.75	2.14 ± 0.25	2.68 ± 0.06	1.32 ± 0.44

One-way analysis of variance between sports on each of the measured parameters, both dependent and independent, showed significant differences between some groups for weight, leg volume, lean body mass, PPO(R), MPO(R), WIN R, PPO, MPO, PPO(WIN) and MPO(WIN) using Scheffé post-hoc analyses (Appendix: F). An examination of the anaerobic group showed gymnasts to be lower than volleyball players and the aerobic group was significantly lower than the volleyball players, basketball players, and track/field athletes in terms of power production ($\alpha = 0.05$).

For the step-wise regression analysis, for preduction of the force needed to elicit PPO and MPO, a correlation matrix was established (Appendix: D-I). In the statistical analyses, the addition of an independent variable to the predictive equation was based on whether that addition increased the multiple R and the regression of force on the independent variables in the equation remained statistically significant. In addition to an increased multiple R the independent variable was examined for the statistical significance of its addition at the 0.05 level. The decision to reject the addition was based on no increase in the multiple R, non-significant F ratio for the equation and/or independent variable and large increases in the standard deviation of the residuals (see Appendix: E-I and II for regression analyses).

The resulting equations to predict PPO(R) and MPO(R), utilizing anthropometric data, were respectively:

1. PPO(R) = 1.2899 + 0.1836(TC) - 0.2378(CC) + 0.0301(WT)
   where multiple R = 709 ($p < 0.05$) and standard error of estimate (SEE) = 0.581 kp.
2. MPO(R) = 0.8624 + 0.1316(TC) - 0.1502(CC) + 0.03511(WT)
   where multiple R = 0.726 ($p < 0.05$) and SEE = 0.510 kp.

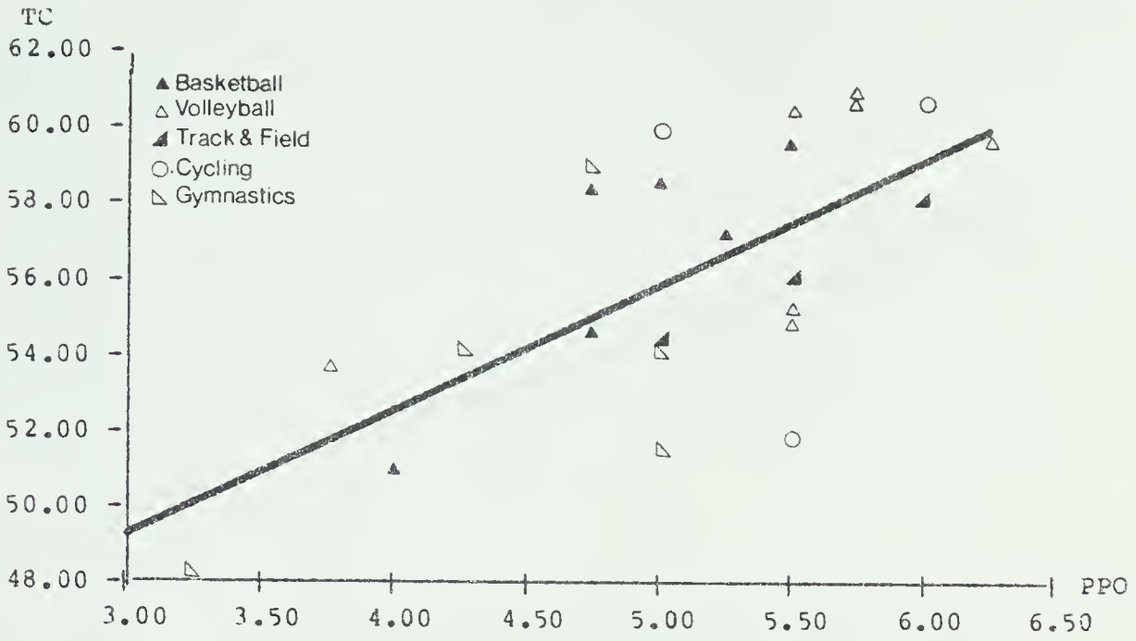
The linear relationship of independent variables to the dependent

variable are shown in Figures 3, 4 and 5 while Figure 6 shows the relationship of the predicted R to the measured R for both PPO and MPO. The independent variables used as predictors were highly associated. Used individually as predictors of force, they resulted in a reduced multiple R, increased the probability of the F ratio occurring by chance, and increased the standard error of estimate (SEE).

Examination of the residual plots for the force that actually elicited PPO or MPO minus estimated PPO(R) or MPO(R) versus PPO(R) or MPO(R), TC, CC, and WT showed no deviations larger than one standard deviation and/or the standard error of estimate (SEE) (Appendix: D-II to V).

For the purpose of validating the prediction equations, a cross-validation procedure was adopted utilizing a screening sample (n = 10) and a calibration sample. The differences between R^2 values obtained from prediction equations and the pearson correlation between obtained and predicted values were examined (Appendix: G) and showed the difference between these R^2 values to be minimal. This finding demonstrated that little difference existed between the screening and calibration sample and therefore permitted them to be combined for predictive purposes. Kerlinger et al. (1973) pointed out the fact that extra stability is gained. For predictive purposes this study adopted this procedure.

Results of analysis of the five blood samples taken from 6 subjects (one from each sport group) are graphically represented in Figure 7(a) to (f) and show the extent to which the blood lactic acid concentration changed from rest to completion of the anaerobic exercise. Variability for the assay as demonstrated by analysis of 12 mg %, 36 mg % and 60 mg % standards were 4.16%, 1.96% and 1.87% respectively (r = 0.9996, significant at the 0.05 level). Pipetting variability for the assay was 2.34%



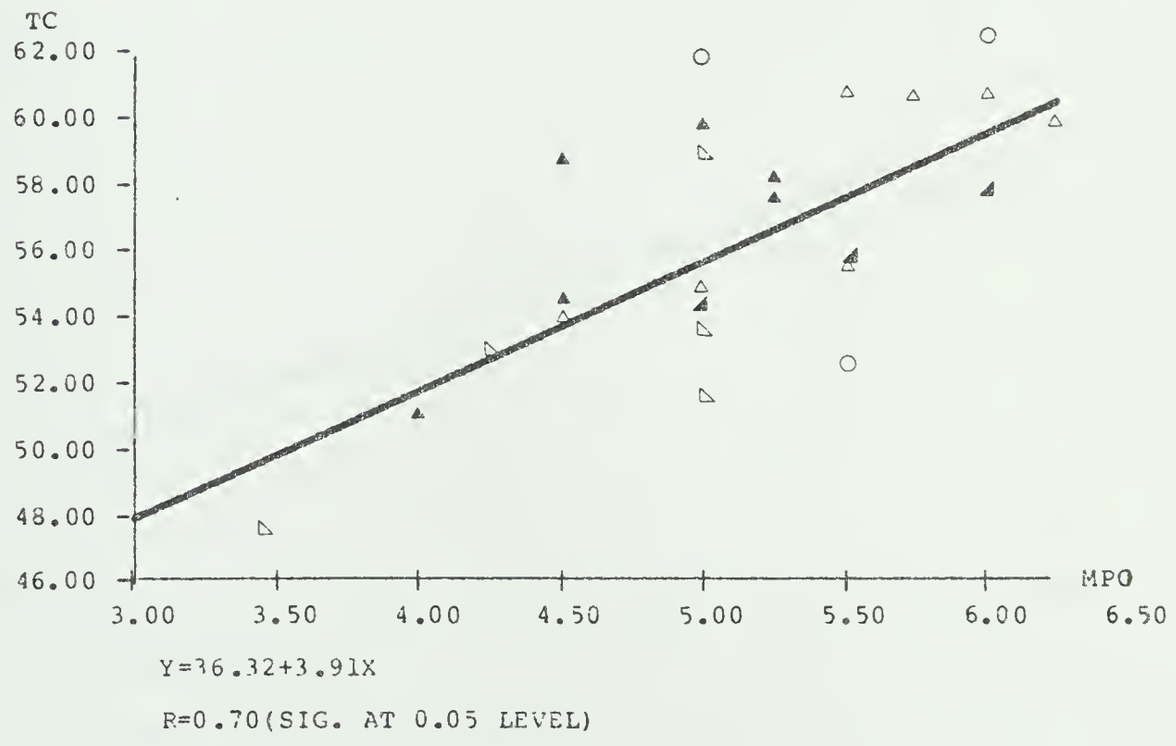
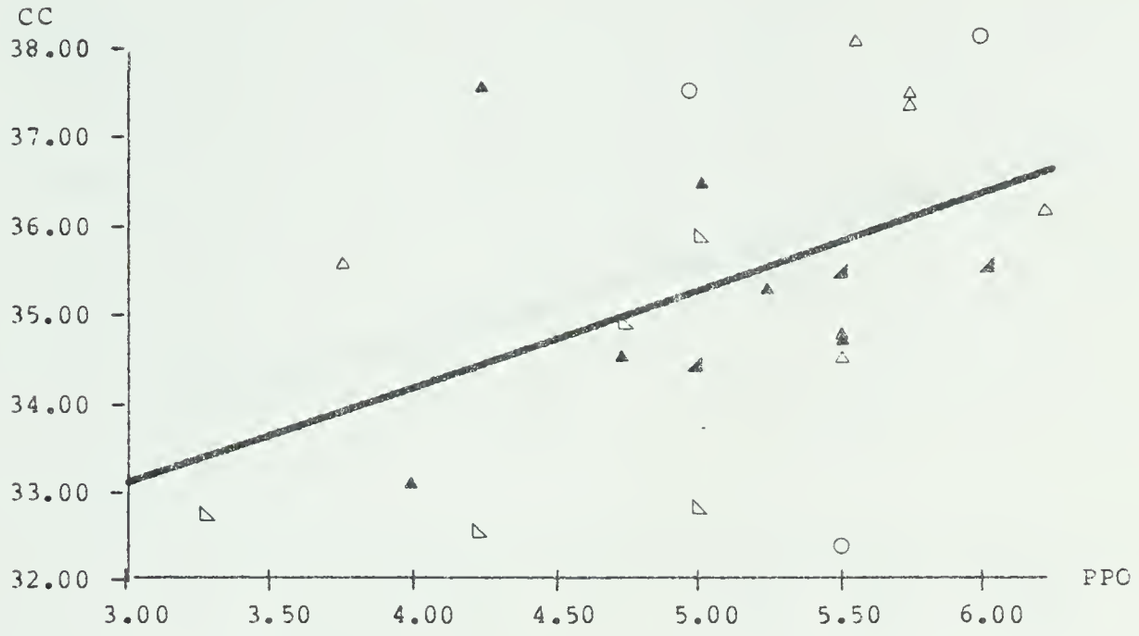


Figure 3. Thigh Circumference As It Relates to the Force To Elicit Peak Power Output (PPO(R)) and Maximal Power Output (MPO(R))



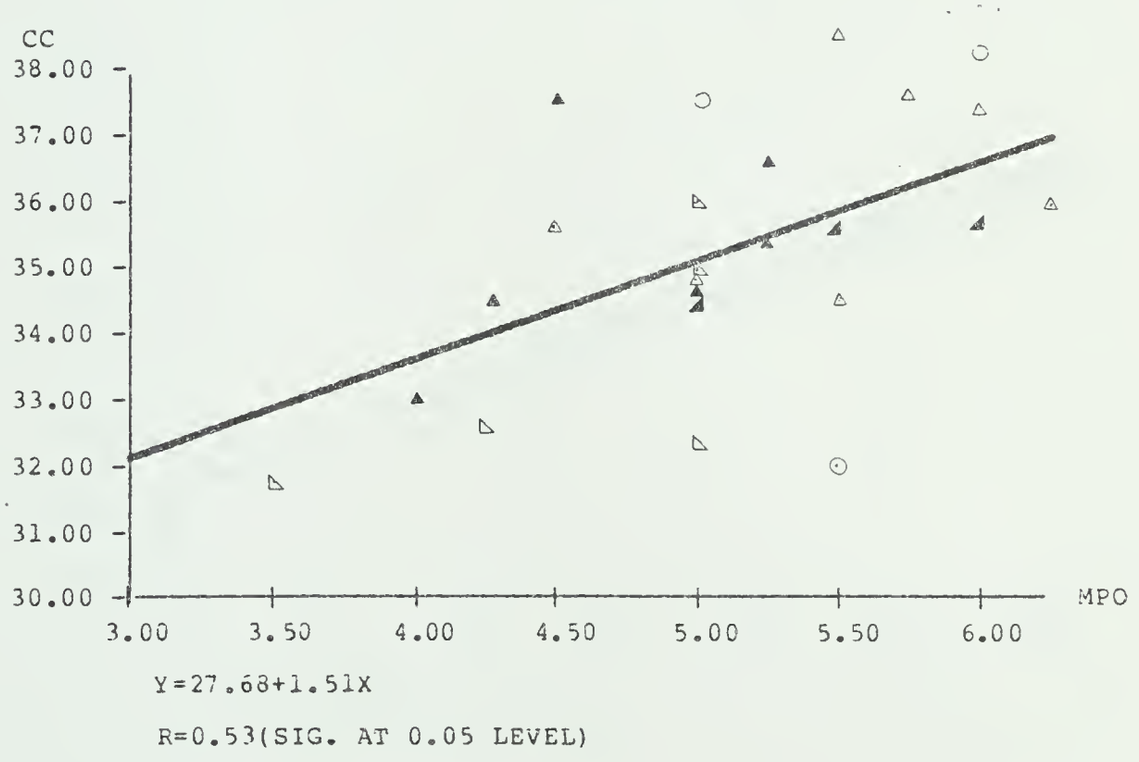
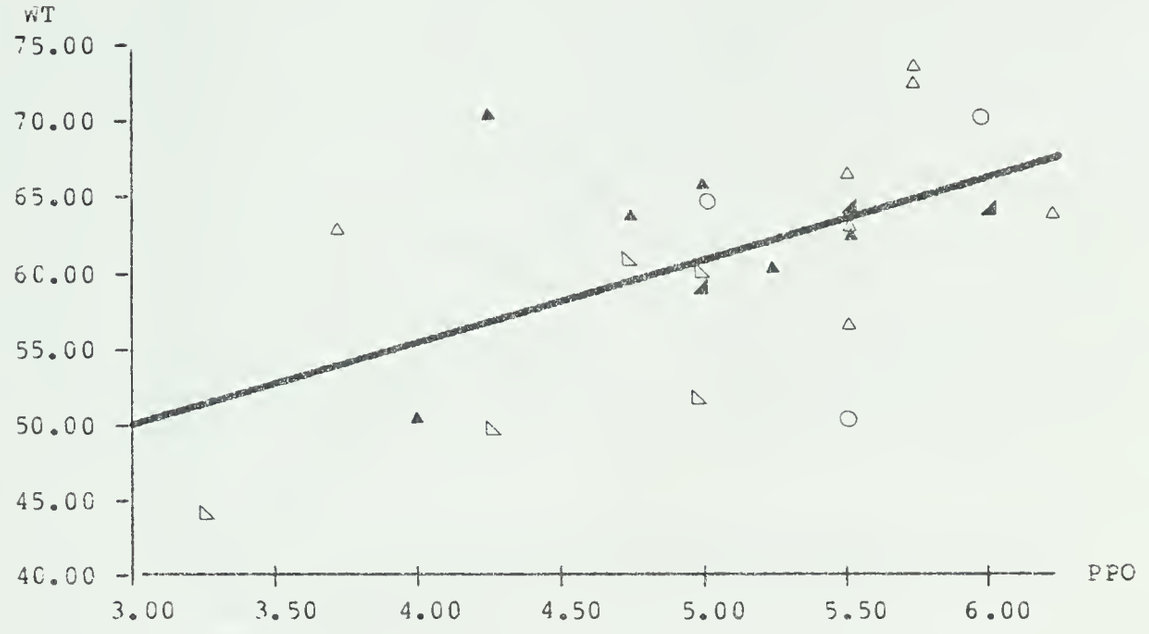


Figure 4. Calf Circumference As It Relates to PPO(R) and MPO(R) As Per Figure 3



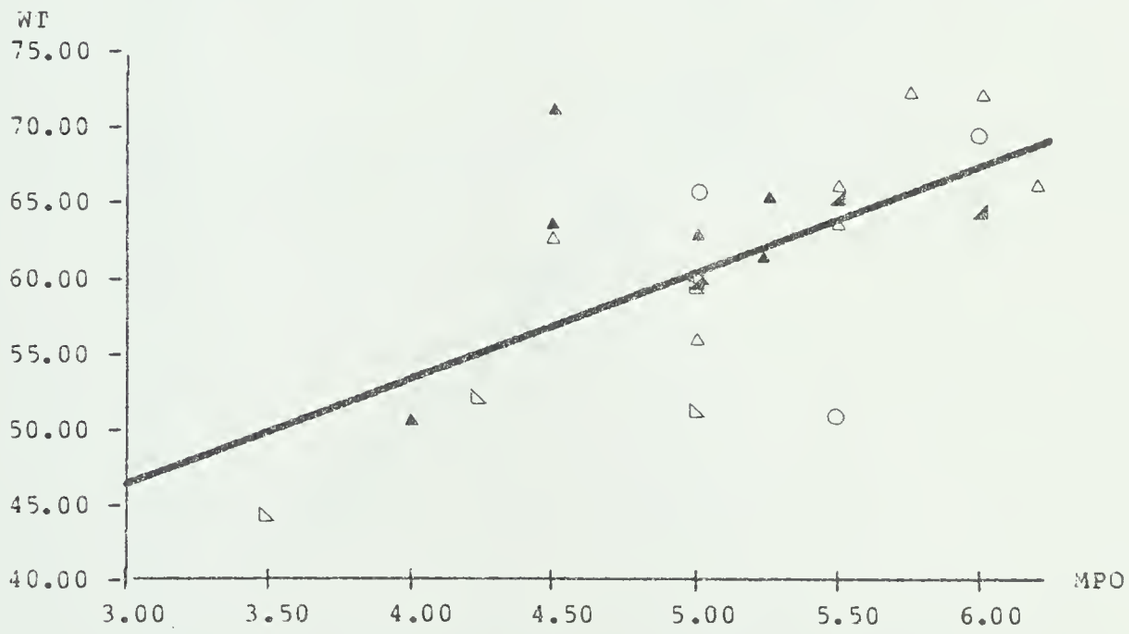


Figure 5. Weight As It Relates to PPO(R) and MPO(R) As Per Figure 3.

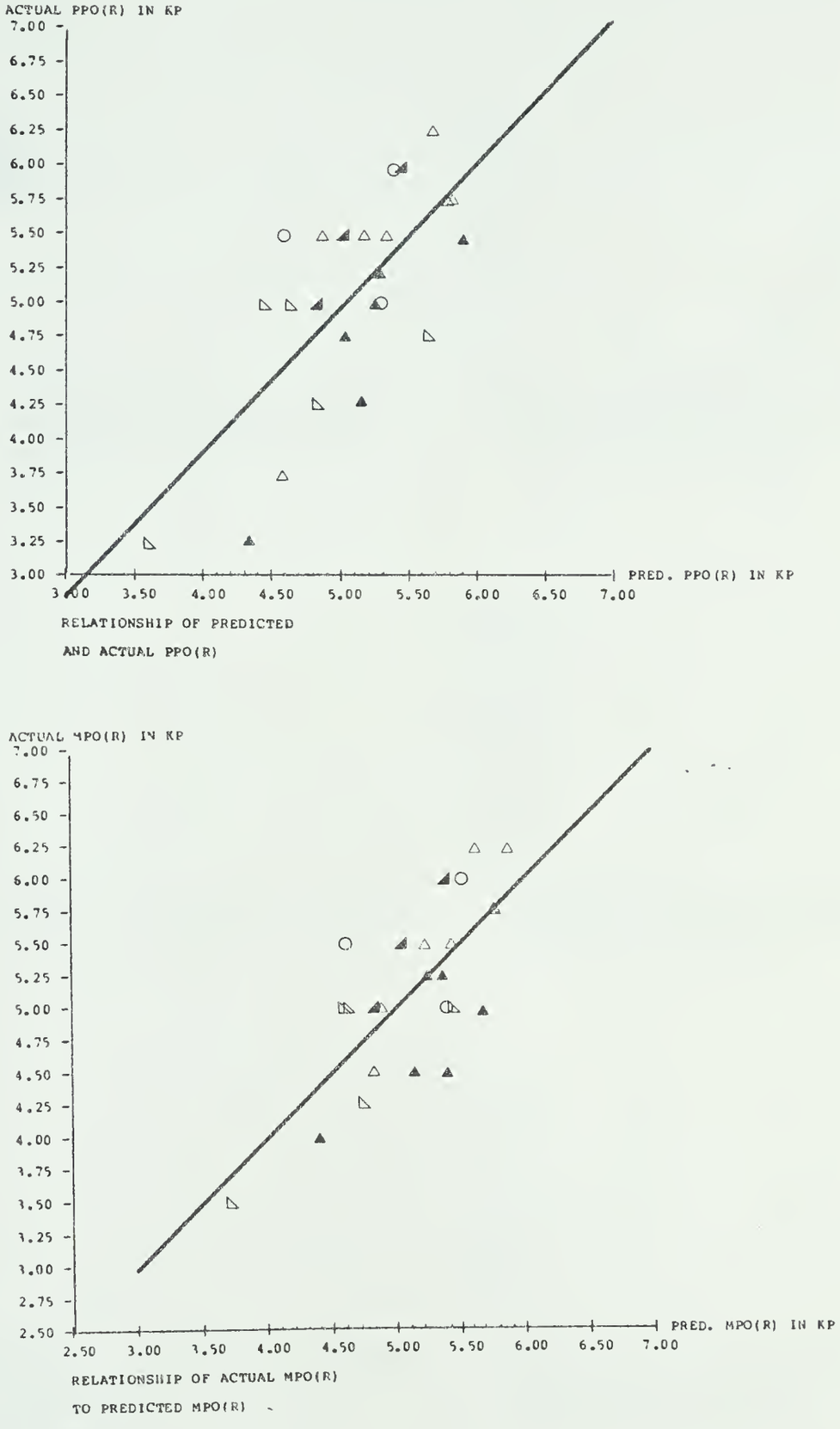


Figure 6. The Relationship Of Predicted PPO(R) and Measured PPO(R) and the Relationship of Predicted MPO(R) and Measured MPO(R)

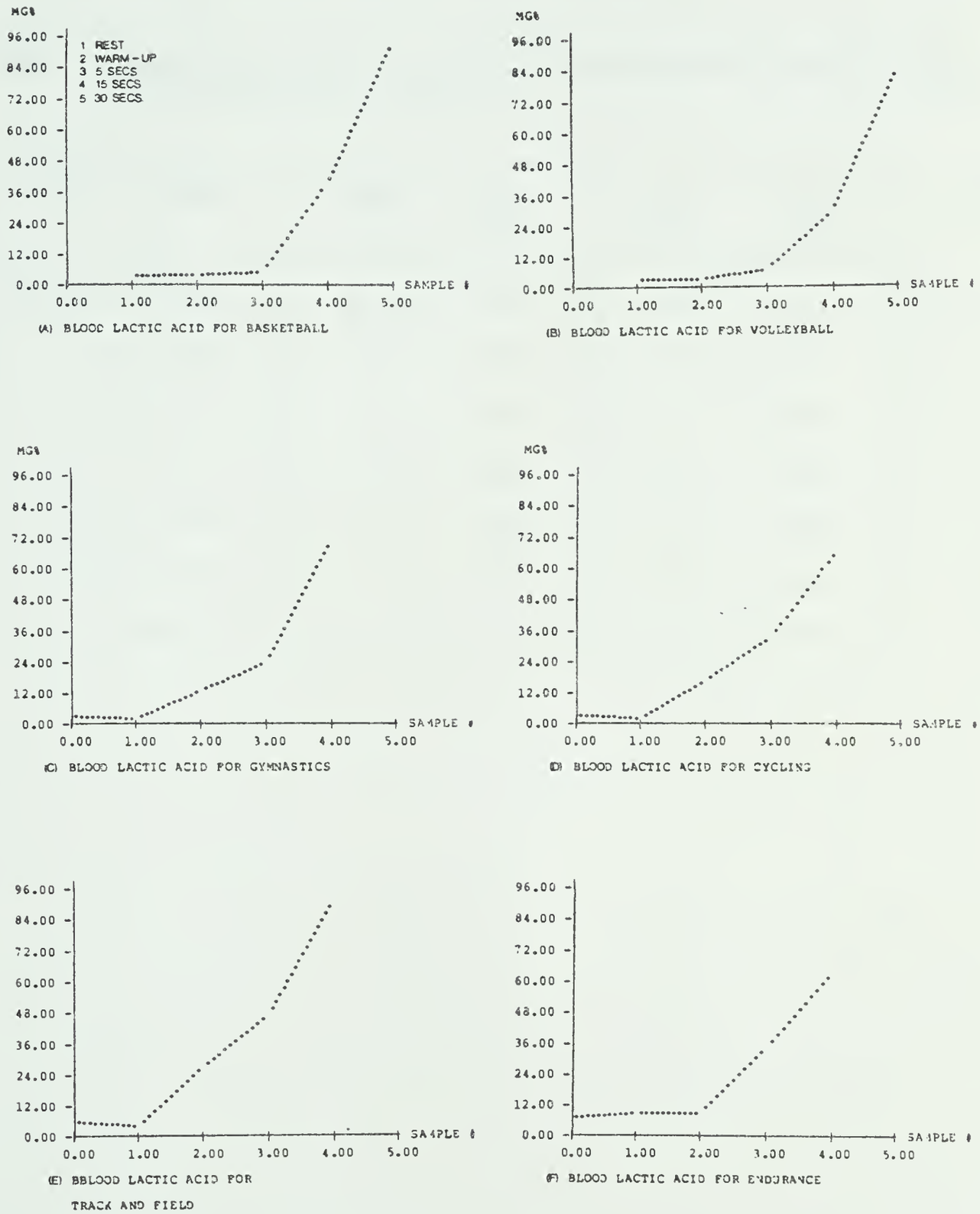


Figure 7. Blood Lactic Acid Changes Versus Time for the Anaerobic Power Test (MG %)

(Appendices: H-I and II).

Haematocrit values in Table V were used to correct lactic acid concentrations for haemocentration due to exercise.

TABLE V. Haematocrits for Five Stages of the Anaerobic Power Test for Each Experimental Group (%)

SAMPLE	REST	WARM-UP	5 SECS.	15 SECS.	30 SECS.
Group 1	39	40	44	46	44
2	41	39	40	42	42
3	42	43	43	42	45
4	37	37	38	41	41
5	40	41	40	40	42
6	41	42	42	45	43

CHAPTER V

DISCUSSION

To optimize power output on a 30 second all out bicycle ergometer test, both in terms of ability to produce peak power output (PPO) and/or mean maximal power output (MPO, a favourable combination of force (resistance setting) and velocity (rpm) is required. Examination of such phenomena for a large number of individuals over many trials has shown there to be a uniqueness of ability to produce power (Force x Velocity) and this is particularly evident in the individual power output curves. No particular association was found between MPO or PPO and pedal speed achieved. On the other hand resistance and PPO/MPO were significantly correlated and the data suggested that velocity or speed of pedalling may be a dependent variable in production of power. Mean pedal velocity for all anaerobic subjects was approximately 95.4 $\pm$ 13.1 RPM and 95.5 $\pm$ 12.97 RPM (for PPO and MPO, respectively). The product of force and velocity account for all power output measured in this study. However to optimize accuracy of prediction, bracketing of velocity within the above range would optimize performance.

Departure from the classical force/velocity curves (Hill, 1938) as demonstrated in this and other studies (Cavanagh et al., 1971; Wilkie, 1950; Sjogaard, 1970), can be explained in the interplay of optimally loading force and velocity (Seabury, 1977) and overcoming friction. This interplay was exemplified in the observation of rpm elicited for the first 5 seconds of the all-out power test, particularly for a number of the lower resistance settings. Pedal speed remained the same regardless of any increase in resistance. On an interindividual basis, equivalent power output could be achieved by either greater pedalling

frequency and lower resistance setting or vice versa.

This phenomenon appeared to be sport related and the data suggested it was especially advantageous to obtain higher power outputs via increased pedal frequency rather than by working against increased resistance. This can be explained by the negative work that occurs in the up phase of the pedal cycle where the elastic components of the muscles involved in the exercise are able to store energy as potential energy for the next down phase (Sjogaard, 1978). Consequently, any increase in speed would result in increased total negative work, increased potential energy, and therefore, aid in the production of force for the down phase (Luthanen and Komi, 1980). The bicycle ergometer test may thus appear to be advantageous for those athletes who have a disposition towards recruitment of fast twitch fibers rather than slow twitch or from the muscles utilizing a greater percentage foot twitch.

> It is well established that the peak efficiency of fast twitch muscle fibers occurs at much higher contraction velocity than that of ST muscle fibers. Consequently this had led to the finding that mechanical efficiency in bicycle ergometer work varies due to the combined effect of the load, muscle fiber composition and pedalling rate (Komi, p. 44, 1982).

In fact, electromyographical studies have shown that in activities which utilize stretch-shortening cycles, the concentric contraction can be performed through recoil of elastic energy and with very little expenditure of electrical and chemical energy (Komi, 1982; Lutahnen, 1980). Mechanical power measurements in particular muscle groups revealed peak power values of the concentric phase to occur at different contraction speeds depending on the relative distribution of FT and ST fibers in the muscle. Predominantly FT type muscle showed speeds of 12 $rad.s^{-1}$ or higher while ST type muscle was as slow as 3-4 $rad.s^{-1}$ (Komi, 1982).

Compared to aerobic testing, where lower resistance settings and longer exercise durations are predominant, the power test utilized in this study was of an anaerobic nature in that it required an all-out effort over 30 seconds (barely enough time for aerobic mechanisms to fully kick in). Since no steady state is achieved, it is feasible to examine decrements in power output over the exercise period depending on the particular sport and its length. Examination of individual power curves showed these decrements and were similar to those reported by Katch et al. (1977). The peak usually occurred in the first 5 seconds and similarly to the Margaria stair run (1966) reflected utilization of ATP from the ATP-PC system. It was noted that this was peak for a 30 second test and cyclists appear to have no advantage over other athletes due to the specific nature of the exercise. This was evident in comparison of the relative power outputs (10.05 watts/kg and 7.63 watts/kg).

For impulse events which required a single maximal contraction which may be equated in the current study with a down phase of the pedals, measurements of between 230-420 kp have been reported (Sjogaard, 1978). This study was however concerned with ability to produce power in a 5 and 30 second time period but if a single maximal contraction was equated with a single down stroke of pedalling then values in the vicinity of 393 kp were measured (i.e., 5 seconds/12 revolutions thus 0.42 secs/revolution).

A range of absolute settings, the weight-relative Wingate setting and the full range of resistance settings (and consequent pedal frequencies) to elicit MPO and PPO for each individual was completed. These measurements were obtained in every case and the standard absolute settings and the Wingate protocol were significantly different ($\alpha = 0.05$) to PPO(R) and MPO(R). This may be attributable to the fact that a highly anaerobically

trained group were tested. The protocol devised at the Wingate Institute did not test competing university athletes in determination of the protocol.

Testing of each subject was completed within a two to three week time period so reproducibility as shown by test-retest data was good. For testing beyond this time period, functional changes and/or effects of training (or detraining) have not been examined and therefore may make long range anaerobic power testing a difficult proposition.

Both the correlation matrix and consequent step-wise regression indicated the anthropometric measures of thigh circumference and calf circumference in combination with body weight elicited a predictive equation which accounted for in excess of 50% of variation in PPO and 52% of variation in MPO. Measurement of PO beyond a 3 week time frame may result in dramatic changes as fitness level, motivation, diet and stress may alter performance.

The high degree of association of WT and LV pre-empted its inclusion as a predictor. In fact it (LV) was the last variable to be accepted into the equation for just this reason. With regard to utilizing WT versus LBM as a predictor, examination of the correlation matrix showed WT to be better correlated with the dependent variable or criterion and significantly increased the multiple R for the regression ($\alpha = 0.05$).

TC, CC and WT are all measures that can be expediently measured and despite some degree of association, their addition to the equation was significant ($\alpha = 0.05$) and suitably increase the multiple r value.

For any work involving prediction, larger sample size will decrease the likelihood of chance being attributed to the relationship. Hence for this study, greater creedence could be placed on the results if the sample

size were increased. Despite this shortcoming, all other assumptions of multiple regression analysis appear to have been satisfied. Anthropometric data regressed against PPO(R) show linearity and are significantly greater than zero ($\alpha = 0.05$). This holds true for MPO(R) also. Residuals plotted against PPO(R) and MPO(R) showed independence and a homogenous variance about a zero mean. The anthropometric data appeared normal and the cross validation procedure demonstrated shrinkage to be relatively small. To this end combining the split sample was thus permitted as an increased sample size increases stability (Kerlinger and Pedhazur, 1973).

Reasoning behind developing two predictive equations was to determine if similar anthropometric attributes correlate with power production for 5 seconds compared to the 30 second period.

Davies (1971) supported the notion that leg muscle size and overall body size significantly related to anaerobic power production assessed by maximal jumping, stair running, and aerobic bicycle exercise.

Peak power and % FT fiber composition were good predictors of performance in a 40 meter sprint ($r = 0.72$) whereas both total power output and peak power output were better ($r = 0.72$) for 300 meter performances (Inbar et al., 1979). The need to provide information regarding performance for various phases of the 30 second test was evident and measurement of PPO and MPO would provide this type of information when equated with field performance. Skinfold measures in this study did not give any indication of being either detrimental or beneficial to performance. Since bicycle ergometry is a weight supported mode of exercise the effects of non-contributing body mass is minimal. This is not however the case in the Margaria stair run where increased WT also increased power output (Caiozzo et al., 1980).

It is not surprising, then, that the same parameters were selected for addition to the prediction equation and only the respective weightings and constants differ. This suggests that peak power output and MPO differ only in that some athletes are more suitable to particular event lengths than others. To emphasize this point, the ANOVA showed significant differences between the aerobic group and some of the anaerobic groups on PPO, MPO, WIN(R), PPO(R), MPO(R), MPO(WIN) and PPO(WIN). Significant differences between the gymnasts and volleyball players suggest too that event time and type are key factors in prediction of performance. A gymnast is required to perform a series of maximal exercises lasting from 5 seconds to 1½ minutes whereas a volleyball player may be required to produce many single maximal jumps interspersed with a rest period. Therefore a test of peak performance would be more beneficial for a volleyball player than a gymnast. This notion is supported by Margaria (1966) who showed that no rest was needed between performance on the stair test because of its highly anaerobic nature.

From examination of the prediction of power output by anthropometric data and actual PPO, it was apparent that this regression better predicted performance for basketball, gymnastics and track and field whereas MPO was better predicted for the aerobic events, cycling and gymnastics. This finding would be expected if the duration of events and the intensity of these events are considered. These observations give strong support for the need to be able to test portions of anaerobic power in conjunction with the duration of an event (e.g., 100 meter sprint, long jump). A comparison of prediction of PPO(R) and MPO in relation to competitive performance would substantiate this even further.

Aerobic groups in general do not perform as well in anaerobic power tests (Taunton, 1980; Komi et al., 1977) and this study also exemplified

this finding. Aerobic athletes tended to have a low PPO and drop off was as low as 30% compared to approximately 60% for some anaerobic athletes. This phenomena certainly adds credence to the notion of the anaerobic system being trainable. That no significant differences were found in the anthropometric data certainly suggests changes must be occurring at a cellular level rather than anatomically as far as training regimes are concerned. Comparison with a larger aerobic group would however be wise to substantiate this lack of difference. Data from this study suggested the parameters needed to predict MPO and PPO for anaerobic athletes were not good predictors for aerobic athletes. Performance was over estimated. Using a less conservative analysis than the Scheffé post hoc analysis and an equal sample size would also enhance any conclusions drawn.

One would suspect that because circumference measures predominated in the prediction equation that this is an indication of muscle mass and/or the fact that an anaerobic athlete tends to have a larger population of fast twitch fibers. Certainly the fact that significant differences were found between leg volume, LBM, and WT for gymnastics versus volleyball suggested that muscle mass or body size was an important factor in the production of anaerobic power. Although the high intensity 30 second test predominately engaged leg muscles, involvement of upper body muscles for stability was evident. This may possibly enhance performance in anaerobic power tests. For males (Evans, 1980) body weight and leg volume accounted for 15, 27 and 56% of variance in power outputs. In this study WT and LV accounted for 39% and 0.1% of variations. LBM accounted for 5-10% variation.

Fast twitch fibers greater in cross-section area (Saltin, 1973) therefore would result in larger circumference measurements. Also the

fact that FT fibers are trainable may enhance musculature (Gollnick, 1972; or Karlsson, 1970).

A larger population of FT fibers would also explain the relatively higher blood lactates in acid levels found for some anaerobic athletes compared to the aerobic since fast twitch fibers are largely responsible for the production of lactic acid (Costill et al., 1970). The effect % FT fiber type has on power output is to influence glycolytic capacities of the overall muscle and hence anaerobic performance.

Lactic acid analysis confirmed the 30 second power test as anaerobic in nature and while some difference was seen between the aerobic and anaerobic group, generalizations about trends for particular sports groups cannot be made. Similar increased in haemoconcentration occurred for all athletes. It must be noted that all samples were not taken on the same day therefore despite the subjects being in a 2 hour post prandial state some differences due to dietary changes may effect basal and exercise levels of blood lactic acid and extent of haemoconcentration. This decrepancy is witnessed in warm-up (lactic acid levels) being lower than resting levels. Metabolism of LA by SO muscle and cardiac muscle may also account for this drop since sampling took place 5 minutes post exercise.

Evidence from this study does suggest a 30 second anaerobic power test can reveal valuable information about performance as it relates to sport type. The availability of equations to predict force settings to elicit PPO or MPO will circumvent the long process that was required to establish both of these measures. WT, CC and TC are easily measured and a one trial test of 30 seconds is simple to administer. To this end, testing a maximal 30 second effort would be more appealing to the athlete than numerous testings requiring such maximal efforts.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of this study was to develop procedures to predict the resistance required to elicit both PPO and MPO on a 30 second bicycle ergometer test by means of regression equations. Anthropometric measurements were the basis for this prediction.

Twenty-four highly anaerobically trained athletes (Basketball, Volleyball, Gymnastics, Cycling, Track and Field) and four aerobically trained (long distance runners) female athletes were measured on a series of lower extremity and total body anthropometric measures. This was followed by a series of 30 second all-out ergometer tests utilizing absolute resistance settings of 3.5 kp and 4.0 kp. The weight relative Wingate setting and increasing resistance settings thereof were also administered until PPO and MPO were achieved. These were established by the plotting and analysis of power versus time to produce a power curve.

Both PPO and MPO were significantly different to the Wingate setting and the fixed resistance settings ($c = 0.05$).

Test-retest reliability for PPO and MPO were respectively 0.96 and 0.99 ($c = 0.05$) and thus predictive equations were established by stepwise multiple regression using selected anthropometric measures.

The equations for prediction of PPO(R) and MPO(R) are respectively:

1. $PPO(R) = 1.2899 + 0.1836(TC) - 0.2378(CC) + 0.301(WT)$

   $R = 0.709$ ($p \leq 0.05$)

2. $MPO(R) = 0.8624 + 0.1316(TC) - 0.1502(CC) + 0.0351(WT)$

   $R = .729$ ($p \leq 0.05$)

Cross validation by use of a screening sample ($n = 10$) and a calibration sample ($n = 14$) showed shrinkage of R to be relatively small and

therefore allowed the sample to be combined for predictive purposes.

In the ANOVA performed to establish differences in measurements of aerobic and anaerobic athletes no significant differences were found in anthropometric measures except weight, leg volume, and lean body mass ($c = 0.050$). Differences were however found between PPO(R), MPO(R), WIN R, PPO(WIN), MPO(WIN) and MPO for aerobic versus some anaerobic athletes. The gymnasts showed some significant differences in both power output and body dimensions compared to volleyball athletes. No other differences were found.

Blood analysis of 6 subjects (one from each sport group) established the anaerobic nature of this 30 second all-out test. Observable trends showed athletes in short duration events to have higher blood lactic acid levels than the aerobic subject. Haemoconcentration averaged a 3% increase.

The following conclusions seem to be justifiable within the bounds of this study:

1. The equations developed show reliability and validity in determining resistance settings for anaerobically trained athletes in an all-out ergometer test.
2. Both peak and maximal power output provide information, as measured by the 30 second power test, about the anaerobic athlete according to her event/sport and its duration.
3. Peak and maximal power output does appear to be sport specific and hence training specific.
4. Short duration events/sports showed a tendency for the athlete to produce higher PPO whereas athletes of longer duration (up to 30 seconds) events were better able to sustain power over the 30 second period.

5. At intensities less than that which produced PPO or MPO power output was anatomically limited and in the case of the latter allowed a higher average power output to be maintained over the test period.
6. Comparison of males and females showed differences from 20-50%, 30% in absolute power output and approximately 2 watts/kg in relative power output.
7. Anthropometric parameters used to predict resistance settings in males are not suitable for females.
8. Blood lactic acid analysis demonstrated the test was of an anaerobic nature and suggested lactic acid levels were generally higher for anaerobically trained athletes.

Implications, Applications and Recommendations

Establishment of equations to predict PPO(R) and MPO(R) provides the coach, athlete or physiologist with a foundation or profile of the type of resistance settings that would be required to elicit maximal responses without the ordeal of performing multiple trials over a number of days. With a point from which to start testing, the power output produced by the predicted resistance need only be bracketed by a slightly lower and slightly higher resistance to pinpoint PPO and/or MPO. Testing athletes between one and three times rather than between seven and 12 times as in this study is infinitely more favourable to the athlete. Motivational and physiological changes in the athlete due to testing and extraneous variables are virtually eliminated.

As indicated by this study anaerobic power is sport specific and body size appeared to be a determining factor in power production for the various anaerobic athletes in this study. Conversely, the same body

structure found in aerobic athletes was not a good determining factor in prediction of power. The formulae therefore appear to be applicable to anaerobic athletes of University to National standard.

Similarly to Margaria (1966) advantages of this 30 second power test are that:

1) Power is easily measurable.
2) No special apparatus is needed apart from a bicycle ergometer and revolution counter.
3) The task is not complex to administer or perform.
4) Recovery from the test occurs rapidly.
5) A large muscle mass is engaged in the exercise.
6) A variety of anaerobic athletes can be tested and training specificity does not appear to alter performance (shown in this study by the performance of cyclists).
7) From a physiological standpoint, highly trained athletes recover quickly and this permits multi-trial testing if needed.
8) Single trial testing is favourable to both athlete and administrator and may provide ongoing information about training regimes and lower body changes as they relate to performance in particular sports.

Two main disadvantages are that performance depends largely on the willingness of the subject and would be applicable to athletes who use the lower extremities for their sport (the usefulness for swimmers has not been researched). Presumably highly trained athletes are usually highly motivated so the former would be reduced somewhat.

Measurement of blood lactic acid levels indicated the distinctly anaerobic nature of this test, and the utilization of high energy phosphagens and glycolytic pathways. Further investigation of metabolic

process is needed. Admittedly a 30 second test only harnesses anaerobic energy sources for that period of time and gives no indication of the exhaustability of this energy system. This was indicated by the ability of some subjects to continue for 3 to 4 seconds beyond the 30 second period. Also the question of reducing resistance to allow continuation of the exercise may give insight as to anaerobic capacities in athletes.

While an attempt has been made in this study to identify power in specific anaerobic groups the following recommendations are suggested:

1) Examination of a larger group of anaerobic athletes to enable a sound cross validation of predictive parameters.
2) The development of norms by means of a population study.
3) Establish the relationship between absolute and relative power output with other anaerobic power tests and the "in field" situations. (Anaerobic power as tested on the bicycle ergometer may be a function of lower body dimensions rather than total body dimensions as is indicated by maximal oxygen uptake tests) Evans, 1981).
4) A double cross validation procedure be utilized.

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APPENDICES

APPENDIX A

MEAN PHYSICAL AND PERFORMANCE CHARACTERISTICS FOR ALL ATHLETES

A-I: Symbols For Appendix

A-II: Mean Physical and Performance Characteristics Of Aerobically Trained Athletes

A-III: Mean Physical and Performance Characteristics Of Anaerobically Trained Athletes

A-IV: Mean Physical and Performance Characteristics Of Basketball Players

A-V: Mean Physical and Performance Characteristics Of Volleyball Players

A-VI: Mean Physical and Performance Characteristics Of Gymnasts

A-VII: Mean Physical and Performance Characteristics Of Cyclists

A-VIII: Mean Physical and Performance Characteristics Of Track and Field Athletes

APPENDIX A-I

Symbols for Appendix

LV	=	leg volume (liters)
TS	=	thigh skinfold (mm)
TC	=	thigh circumference (cm)
CS	=	calf skinfold (mm)
CC	=	calf circumference (cm)
FAT %	=	percent body fat
WT	=	weight (kg)
PEAK R	=	resistance to elicit peak power output (kp)
MAX R	=	resistance to elicit maximal power output (kp)
WIN R	=	Wingate resistance setting (kp)
PEAK/KG	=	peak power output per unit body weight (watts/kg)
MAX/KG	=	maximal power output per unit body weight (watts/kg)

APPENDIX A-II

Mean Physical and Performance Characteristics Of Aerobically Trained Athletes

DESCRIPTIVE MEASURES		MINIMUM	MAXIMUM	MEAN	STD. DEV.
LV	4	8.05	9.90	9.28	1.07
TS	4	10.10	26.60	18.59	7.29
TC	4	47.95	57.65	53.91	4.17
CS	4	7.05	11.50	8.66	1.96
CC	4	32.75	38.00	35.46	2.18
FAT %	4	12.78	21.61	19.05	4.20
WT	4	50.80	63.20	57.13	5.13
PEAK R	4	4.25	4.75	4.44	0.24
MAX R	4	4.00	4.50	4.25	0.20
WIN R	4	4.00	4.50	4.25	0.20
PEAK/KG	4	7.54	10.46	9.19	1.28
MAX/KG	4	6.08	9.16	7.87	1.37

APPENDIX A-III

Mean Physical and Performance Characteristics Of Anaerobically Trained Athletes

DESCRIPTIVE MEASURES		MINIMUM	MAXIMUM	MEAN	STD. DEV.
LV	24	6.90	12.50	9.99	1.51
TS	24	5.40	32.70	18.99	7.07
TC	24	47.30	61.15	54.98	7.33
CS	24	5.40	32.7	19.48	6.85
CC	24	32.20	38.70	35.39	1.94
FAT %	24	9.02	24.12	16.62	3.79
WT	24	44.10	73.20	61.75	7.60
PEAK R	24	3.25	6.25	5.06	0.77
MAX R	24	3.25	6.25	5.10	0.72
WIN R	24	3.25	5.50	4.65	0.57
PEAK/KG	24	7.37	12.06	9.97	1.16
MAX/KG	24	6.22	9.74	7.71	0.82

APPENDIX A-IV

Mean Physical and Performance Characteristics Of Basketball Athletes

DESCRIPTIVE MEASURES		MINIMUM	MAXIMUM	MEAN	STD. DEV.
LV	6	7.90	11.90	10.33	1.34
TS	6	10.05	30.30	18.39	7.24
TC	6	51.05	59.65	56.53	12.99
CS	6	6.40	10.30	8.12	1.38
CC	6	33.05	37.70	35.32	1.66
FAT %	6	13.02	18.60	15.86	2.04
WT	6	50.90	71.90	62.94	6.98
PEAK R	6	3.75	5.50	4.71	0.62
MAX R	6	4.00	5.25	4.71	0.46
WIN R	6	4.00	5.50	4.75	0.50
PEAK/KG	6	8.69	12.06	10.49	1.09
MAX/KG	6	7.18	9.74	8.29	0.83

APPENDIX A-V

Mean Physical and Performance Characteristics Of Volleyball Players

DESCRIPTIVE MEASURES		MINIMUM	MAXIMUM	MEAN	STD. DEV.
LV	7	9.45	12.50	10.70	1.14
TS	7	12.20	29.60	20.74	6.02
TC	7	53.80	61.15	58.16	3.29
CS	7	3.75	12.10	8.19	3.49
CC	7	34.60	38.70	36.41	1.59
FAT %	7	13.54	21.99	18.69	3.12
WT	7	57.25	73.20	65.97	5.52
PEAK R	7	3.75	6.25	5.43	0.79
MAX R	7	4.50	6.25	5.54	0.64
WIN R	7	4.25	5.50	4.93	0.45
PEAK/KG	7	8.38	11.15	10.01	0.98
MAX/KG	7	6.99	8.39	7.62	0.53

APPENDIX A-VI

Mean Physical and Performance Characteristics Of Gymnasts

DESCRIPTIVE MEASURES		MINIMUM	MAXIMUM	MEAN	STD. DEV.
LV	5	6.90	9.55	8.22	1.06
TS	5	5.40	21.15	14.23	6.36
TC	5	47.30	59.10	53.01	4.26
CS	5	2.45	9.40	6.92	2.78
CC	5	32.35	36.00	33.70	1.65
FAT %	5	9.02	15.51	12.78	2.70
WT	5	44.10	60.20	53.04	6.70
PEAK R	5	3.25	5.00	4.45	0.74
MAX R	5	3.25	5.00	4.50	0.77
WIN R	5	3.25	4.50	4.00	0.53
PEAK/KG	5	7.37	11.02	9.19	1.64
MAX/KG	5	6.22	8.51	7.22	0.95

APPENDIX A-VII

Mean Physical and Performance Characteristics Of Cyclists

DESCRIPTIVE MEASURES		MINIMUM	MAXIMUM	MEAN	STD. DEV.
LV	3	7.60	11.65	10.18	2.24
TS	3	13.55	32.70	25.57	10.47
TC	3	51.30	60.80	57.27	5.20
CS	3	8.60	15.15	11.65	3.30
CC	3	32.20	38.40	36.07	3.37
FAT %	3	12.58	24.12	19.12	5.92
WT	3	51.50	69.00	62.65	9.41
PEAK R	3	5.00	6.00	5.50	0.50
MAX R	3	5.00	6.00	5.50	0.50
WIN R	3	4.00	5.25	4.75	0.66
PEAK/KG	3	8.44	10.69	9.62	1.13
MAX/KG	3	6.29	8.80	7.48	1.26

APPENDIX A-VIII

Mean Physical and Performance Characteristics Of Track and Field Athletes

DESCRIPTIVE MEASURES		MINIMUM	MAXIMUM	MEAN	STD. DEV.
LV	3	9.80	10.90	10.48	0.60
TS	3	14.30	19.90	17.47	2.87
TC	3	54.35	58.10	56.07	1.89
CS	3	8.30	12.65	11.10	2.43
CC	3	34.50	35.70	35.28	0.68
FAT %	3	13.50	20.45	17.23	3.57
WT	3	59.80	66.20	63.57	3.35
PEAK R	3	5.00	6.00	5.50	0.50
MAX R	3	5.00	6.00	5.50	0.50
WIN R	3	4.50	5.00	4.75	0.25
PEAK/KG	3	10.27	10.92	10.51	0.36
MAX/KG	3	7.58	8.19	7.83	0.32

APPENDIX B

POWER OUTPUT/FORCE RELATIONSHIPS FOR EACH ATHLETIC GROUP

B-I: Power Output vs Force For Aerobically Trained Athletes (626)

B-II: Power Output vs Force For Basketball (106)

B-III: Power Output vs Force For Volleyball (207)

B-IV: Power Output vs Force For Gymnastics (315)

B-V: Power Output vs Force For Cycling (419)

B-VI: Power Output vs Force For Track and Field (522)

APPENDIX B-I

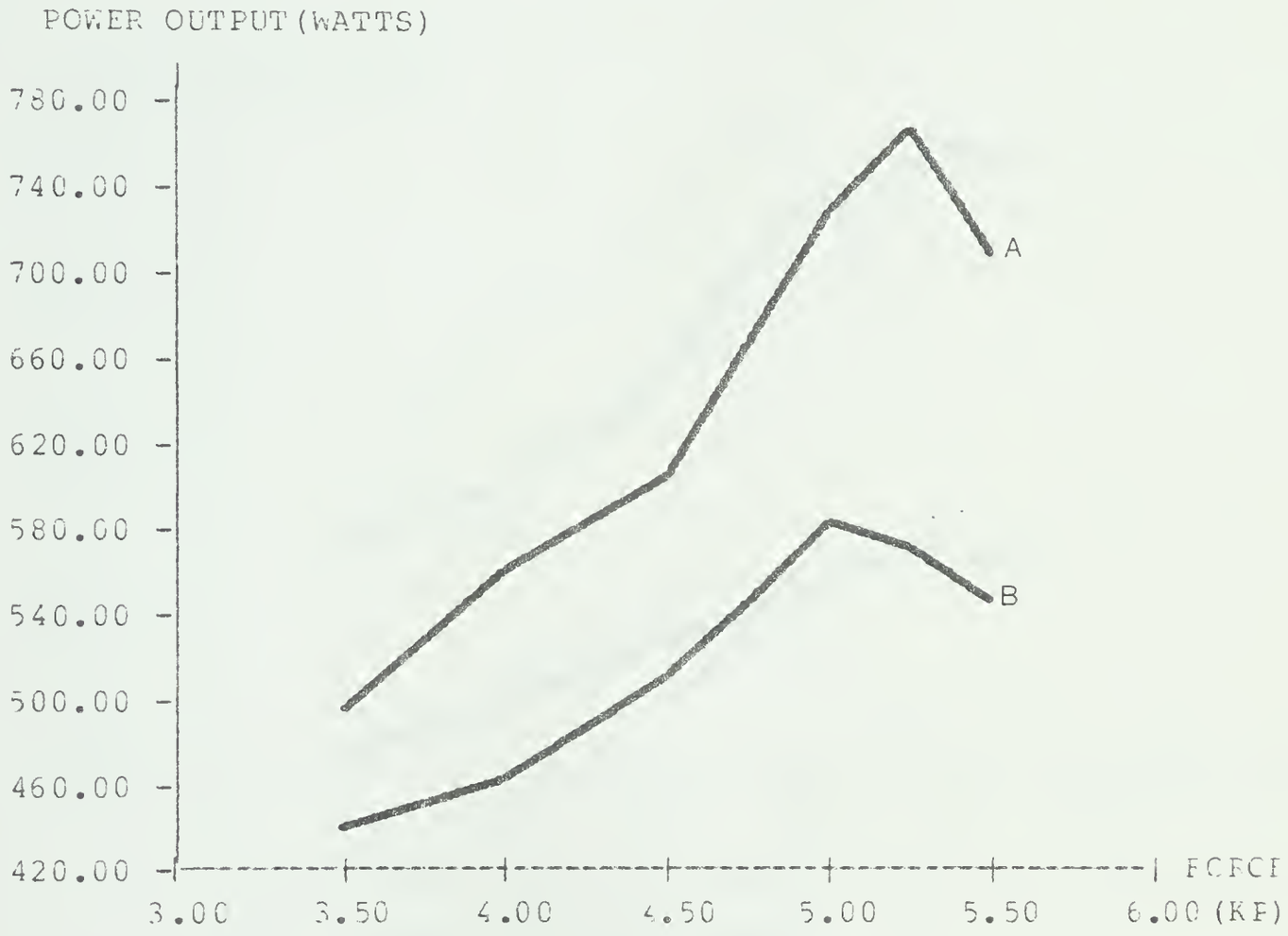
Power Output Vs. Force For Aerobically Trained Athletes

A. PEAK POWER OUTPUT VS. FORCE

B. MAX. POWER OUTPUT VS. FORCE

APPENDIX B-II

Power Output Vs. Force For Basketball



A. PEAK POWER OUTPUT VS. FORCE

B. MAX. POWER OUTPUT VS. FORCE

APPENDIX B-III

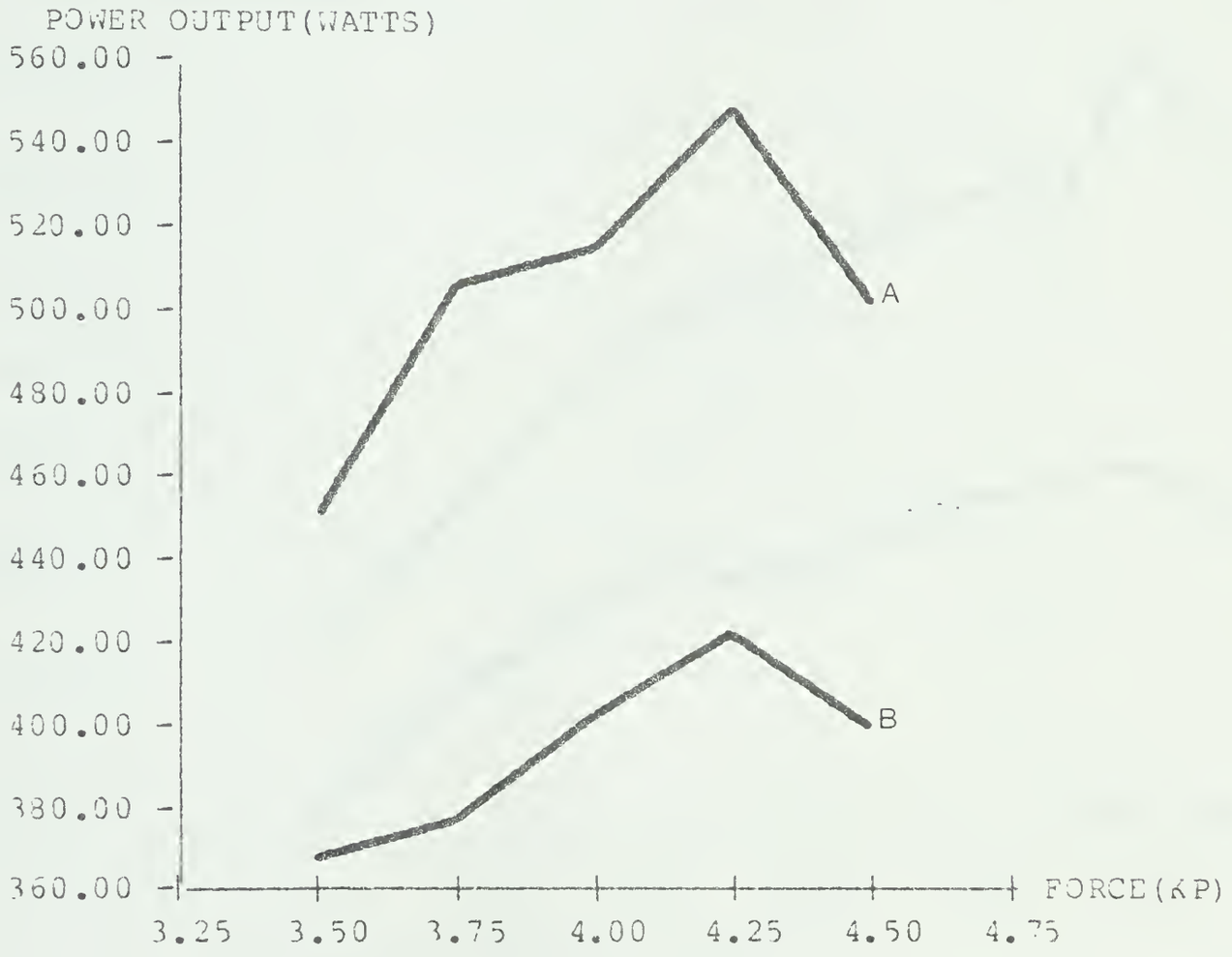
Power Output Vs. Force For Volleyball

A. PEAK POWER OUTPUT VS. FORCE

B. MAX. POWER OUTPUT VS. FORCE

APPENDIX B-IV

Power Output Vs. Force For Gymnastics

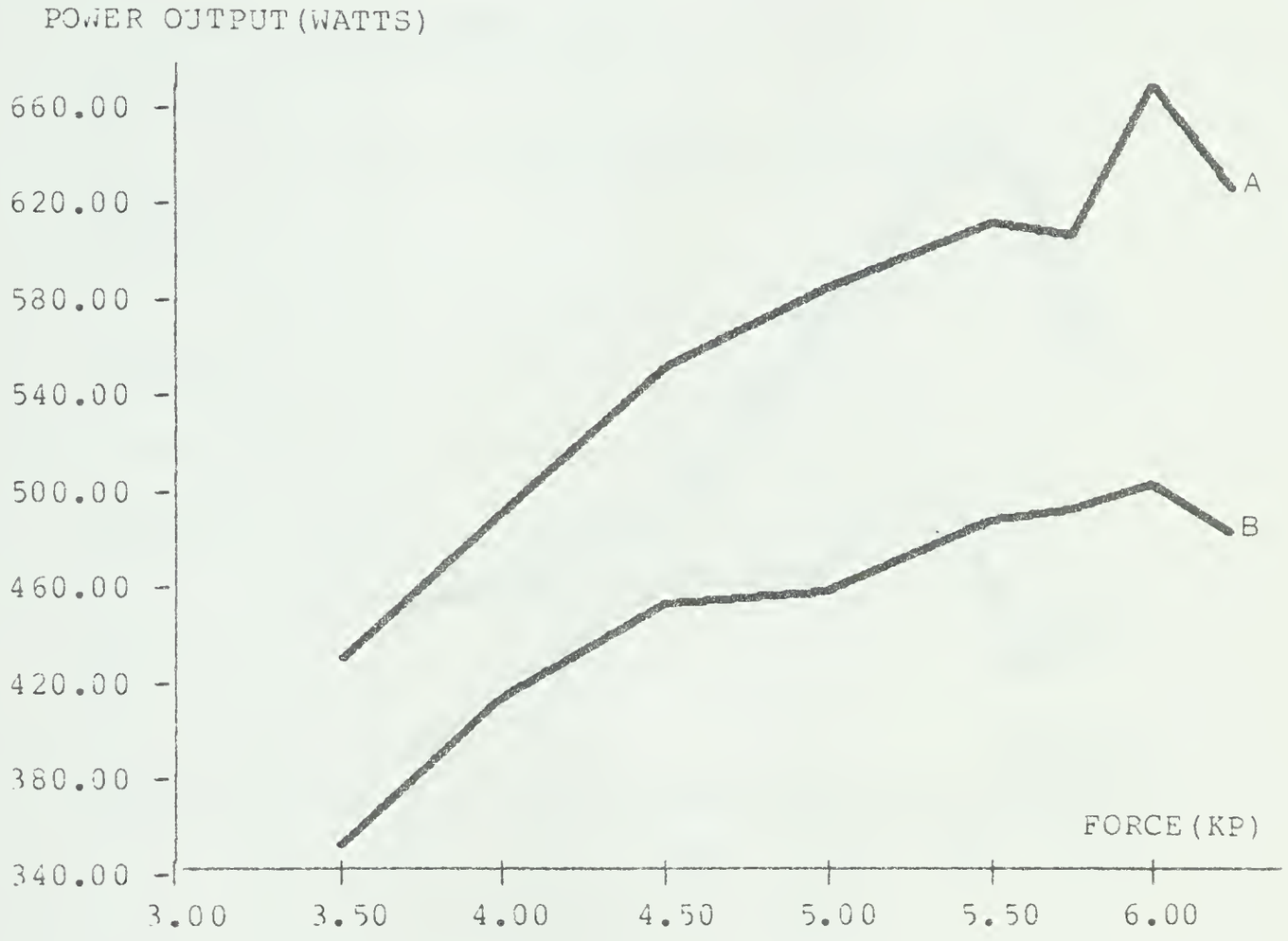


A. PEAK POWER OUTPUT VS. FORCE

B. MAX. POWER OUTPUT VS. FORCE

APPENDIX B-V

Power Output Vs. Force For Cycling

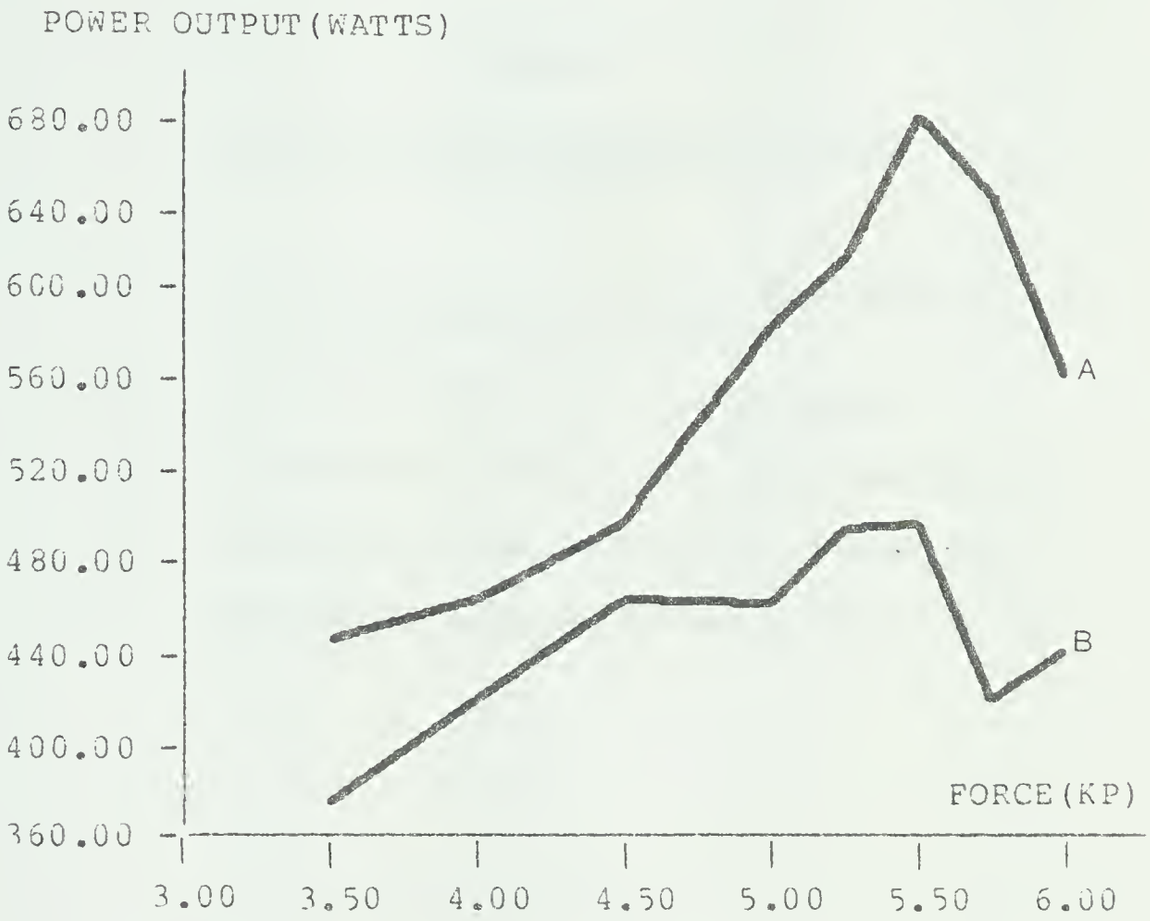


A. PEAK POWER OUTPUT VS. FORCE

B. MAX. POWER OUTPUT VS. FORCE

APPENDIX B-VI

Power Output Vs. Force For Track and Field



A. PEAK POWER OUTPUT VS. FORCE

E. MAX. POWER OUTPUT VS. FORCE

APPENDIX C

RELIABILITIES FOR ANTHROPOMETRIC/POWER OUTPUT DATA

C-I: Reliability For Peak and Mean Maximal Power Output Of Experimental Subjects

C-II: Intratester Reliability For Leg Volume

C-III: Intratester Reliability For Thigh Measurements

C-IV: Intratester Reliability For Calf Measurements

C-V: Measurement Landmarks For Circumference Measures

APPENDIX C-I

Reliability for Peak and Mean Maximal Power Output Of Experimental Subjects

Subject	Test PPO	Retest PPO	Test MPO	Retest MPO
101	671.04	615.12	516.48	503.25
102	676.92	706.32	551.04	551.04
103	625.44	600.37	516.48	506.48
104	507.72	551.76	423.84	435.60
105	647.52	635.64	515.04	510.12
106	741.66	772.56	581.98	576.84
207	712.20	712.20	523.32	512.52
208	529.80	529.80	441.48	441.48
209	679.80	643.08	485.64	490.99
210	643.08	676.92	507.72	541.56
211	710.76	710.76	527.28	527.28
212	662.16	625.44	508.92	484.32
213	647.52	679.83	480.60	485.59
314	447.24	447.24	367.92	354.12
315	550.32	503.28	425.28	401.76
316	618.03	588.60	459.99	446.28
317	529.80	500.28	392.40	387.48
318	317.64	329.64	280.56	281.52
419	671.04	635.64	506.16	515.64
420	550.32	550.32	453.24	428.68
421	559.20	559.20	416.88	402.24
522	647.40	679.80	501.84	501.84
523	706.32	706.32	529.80	523.80
524	618.00	618.00	461.16	461.16
625	575.40	555.60	533.64	526.20
626	531.27	531.24	439.44	441.44
627	476.76	370.80	384.00	384.00
628	475.32	500.28	397.32	425.28
Mean	597.49	590.57	468.91	466.02
S.D.	97.43	104.60	66.38	67.05
% CV	16.31	17.71	14.16	14.39
	$r = 0.95^{*}$		$r = 0.98^{*}$	

Where (a) the hundreds integer indicates the sport:

1 = Basketball
2 = Volleyball
3 = Gymnastics
4 = Cycling
5 = Track and Field
6 = Aerobic

and (b) tens and units represents the subject's number.

*Significant at the 0.05 level

APPENDIX C-II

Intratester Reliability for Leg Volume

Subject	Volume (liters) test	re-test
01	10.40	10.40
02	10.10	10.00
03	9.80	9.60
04	11.10	11.00
05	9.20	9.20
06	10.30	10.40
07	8.90	8.80
08	10.50	10.20
09	10.30	10.00
10	11.20	11.40
11	11.00	10.80
12	8.00	7.80
13	9.70	9.40
14	9.80	9.60
15	11.90	11.40
Mean	10.15	10.00
S.D.	0.98	0.98
% CV	9.60	9.80

$r = 0.91$[1]

[1] r (pearson correlation) significant at the 0.05 level

APPENDIX C-III

Intratester Reliability for Thigh Measurements

Subject	Skinfold (mm) test	re-test	Circum. (cm) test	re-test
01	24.50	25.20	57.80	57.60
02	26.40	24.60	57.00	57.60
03	18.40	18.20	54.70	54.00
04	25.40	26.60	60.60	60.60
05	26.80	26.40	54.50	55.00
06	23.00	21.50	61.20	61.20
07	25.80	25.80	54.90	55.90
08	29.50	30.10	59.30	58.60
09	26.20	28.40	58.50	58.20
10	34.80	36.30	60.70	60.30
11	29.00	30.20	61.20	61.10
12	14.10	14.50	51.00	51.10
13	21.40	20.90	59.20	59.00
14	25.20	24.00	54.60	55.00
15	30.50	30.20	59.60	59.80
Mean	25.40	25.52	57.65	57.67
S.D.	4.98	5.39	3.08	2.94
% CV	19.60	21.10	5.34	5.09
r	$r = 0.98^1$		$r = 0.99^1$	

[1] r (pearson correlation) significant at the 0.05 level

APPENDIX C-IV

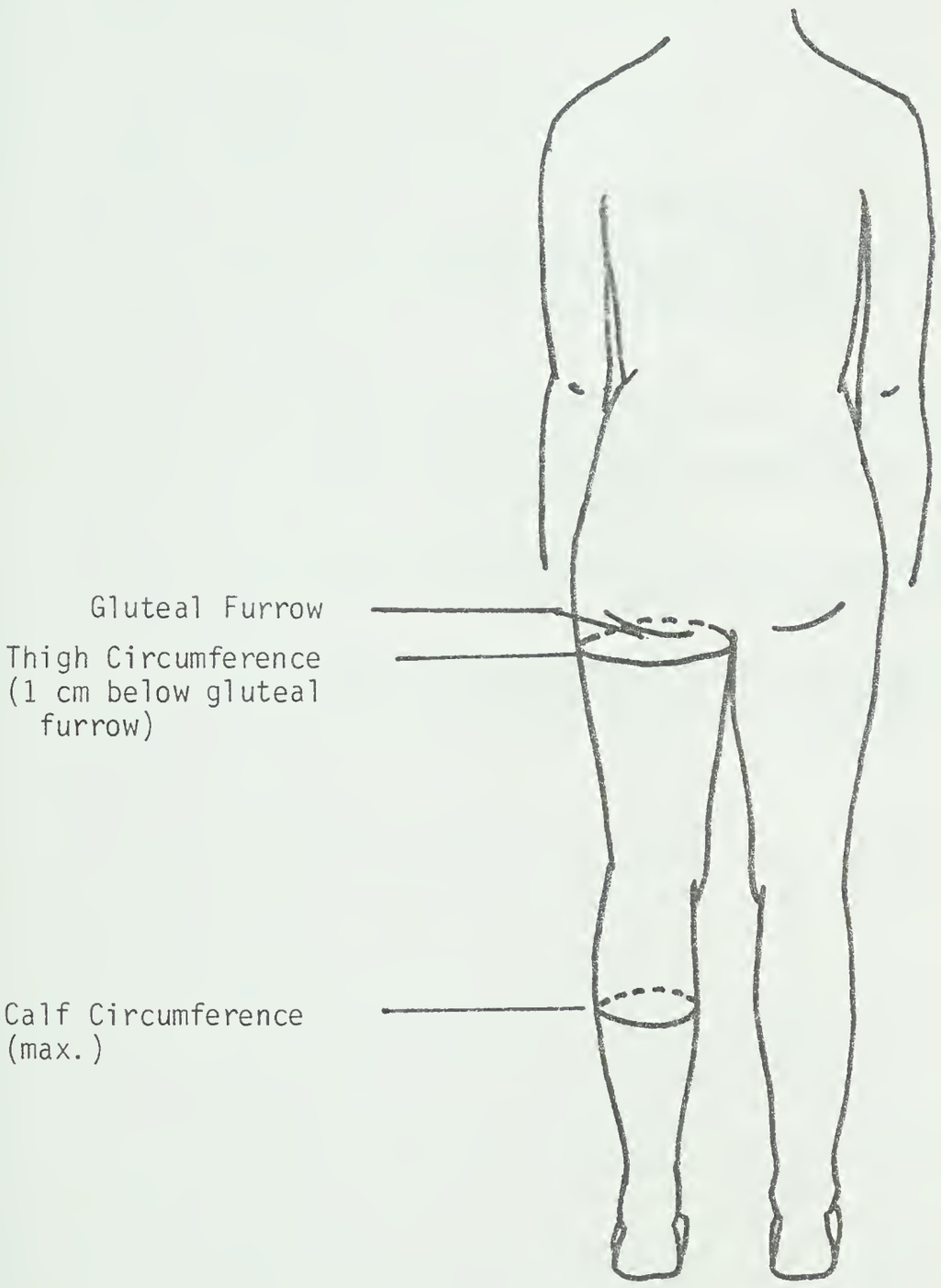
Intratester Reliability for Calf Measurements

Subject	Skinfold (mm) test	re-test	Circum. (cm) test	re-test
01	21.40	19.20	38.00	38.00
02	7.60	7.20	35.40	35.30
03	8.20	8.40	34.50	
			34.50	
04	10.60	11.00	37.50	37.30
05	10.60	12.40	33.00	32.50
06	15.60	15.20	36.60	36.70
07	8.20	9.20	37.10	36.70
08	11.90	11.60	36.40	36.80
09	11.20	11.20	35.60	35.70
10	13.80	14.00	37.50	37.50
11	12.20	12.20	37.70	37.40
12	8.20	8.30	33.00	33.10
13	9.00	8.80	34.90	34.90
14	12.00	12.10	34.60	34.80
15	10.60	11.40	37.60	37.60
Mean	11.41	11.48	35.94	35.92
S.D.	3.56	3.07	1.66	1.69
% CV	3.44	2.97	4.62	4.71
r	$r = 0.98^1$		$r = 0.98^1$	

[1] r (pearson correlation) significant at the 0.05 level

APPENDIX C-V

Measurement Landmarks for Circumference Measures



Posterior View

APPENDIX D

RELATIONSHIPS OF INDEPENDENT AND DEPENDENT VARIABLES

D-I: Correlation Matrix For Regression Analysis

D-II: Relationship Of Weight To Residual (actual PO-predicted PO)

D-III: Relationship Of Thigh Circumference To Residual (actual PO-predicted PO)

D-IV: Relationship Of Calf Circumference To Residual (actual PO-predicted PO)

APPENDIX D-I

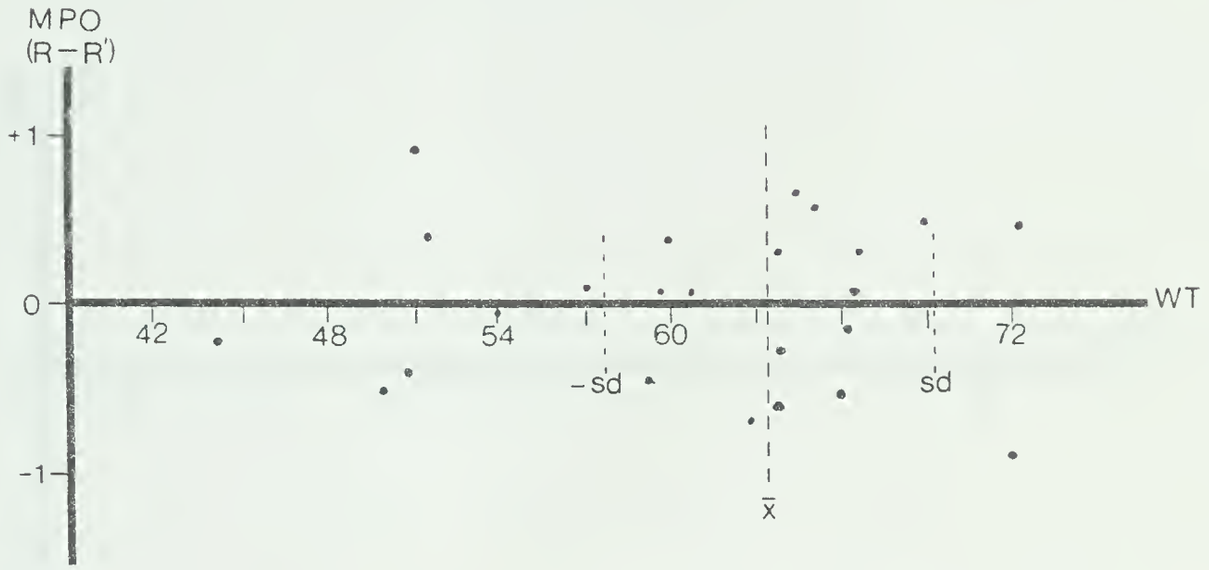
Correlation Matric for Regression Analysis

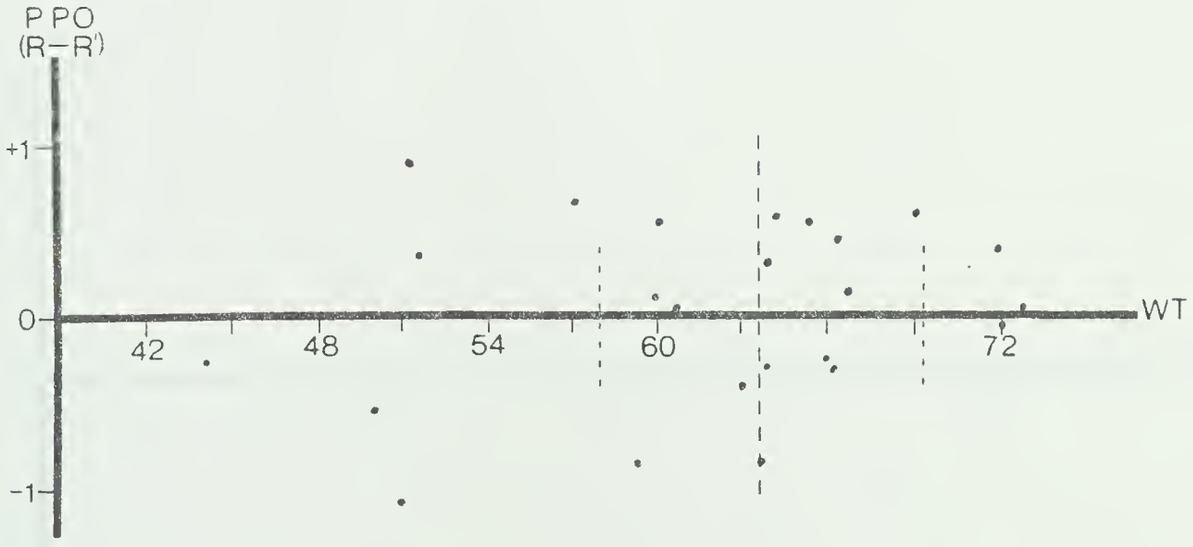
	LV V3	TS V4	TC V5	CS V6	CC V7	LBM V8	WT V9	PPO(R) V10	MPO(R' V11	WIN(R) V12	P/KG V13	M/KG V14
V3	1.00000	0.58157	0.87490	0.43389	0.86452	0.86863	0.94454	0.55687	0.56763	0.92962	-0.03883	-0.18426
V4	0.58157	1.00000	0.71820	0.65165	0.66060	0.45856	0.59715	0.56210	0.55574	0.60576	0.16573	-0.01501
V5	0.87490	0.71820	1.00000	0.49126	0.84229	0.76278	0.86679	0.65840	0.70064	0.86574	-0.00865	-0.14452
V6	0.43389	0.65165	0.49126	1.00000	0.40073	0.19941	0.40237	0.59105	0.53550	0.44079	0.21626	0.04188
V7	0.86452	0.66060	0.84229	0.40073	1.00000	0.76004	0.89160	0.42817	0.53010	0.87003	-0.19596	-0.34820
V8	0.86863	0.45856	0.76278	0.19941	0.76004	1.00000	0.95126	0.43784	0.53523	0.93332	-0.02499	-0.11300
V9	0.94454	0.59715	0.86679	0.40237	0.89160	0.95126	1.00000	0.54777	0.63525	0.98293	-0.03712	-0.16093
V10	0.55687	0.56210	0.65840	0.59105	0.42817	0.43784	0.54777	1.00000	0.93906	0.54628	0.41880	0.26767
V11	0.56763	0.55574	0.70064	0.53550	0.53010	0.53523	0.63525	0.93906	1.00000	0.62661	0.29357	0.14505
V12	0.92962	0.60576	0.86574	0.44079	0.87003	0.93332	0.98293	0.54628	0.62661	1.00000	-0.06353	-0.17858
V13	-0.03883	0.16573	-0.00865	0.21626	-0.19596	-0.02499	-0.03712	0.41880	0.29357	-0.06353	1.00000	0.93542
V14	-0.18426	-0.01501	-0.14452	0.04188	-0.34820	-0.11300	-0.16093	0.26767	0.14505	-0.17858	0.93542	1.00000
V15	0.65670	0.55697	0.61553	0.43864	0.51023	0.66525	0.69381	0.70556	0.67523	0.65694	0.68775	0.54751
V16	0.66267	0.48228	0.61606	0.34508	0.50371	0.72048	0.72317	0.63633	0.62365	0.69109	0.61814	0.56053
V17	0.61829	0.62013	0.60105	0.37617	0.57093	0.64215	0.68541	0.50993	0.51125	0.65792	0.49157	0.36661
V18	0.65400	0.53036	0.61630	0.30839	0.54843	0.71232	0.72156	0.54480	0.55746	0.68460	0.52120	0.45956
V19	0.38865	0.33205	0.38677	0.15722	0.29192	0.48262	0.45675	0.30550	0.26991	0.40328	0.58534	0.57825
V20	0.35486	0.33140	0.37104	0.17423	0.28129	0.47203	0.44976	0.27868	0.27562	0.41160	0.61986	0.60003
V21	0.48005	0.32342	0.45645	0.06832	0.36579	0.54710	0.52588	0.33036	0.28778	0.49563	0.49392	0.52568
V22	0.50574	0.33966	0.48944	0.16506	0.37021	0.62116	0.58882	0.36055	0.35503	0.57386	0.50383	0.51470

	PPO V15	MPO V16	WIN PPO V17	WIN MPO V18	p3.5 V19	p4.0 V20	m3.5 V21	m4.0 V22
V3	0.65670	0.66267	0.61829	0.65400	0.38865	0.35486	0.48005	0.50574
V4	0.55697	0.48228	0.62013	0.53036	0.33205	0.33140	0.32342	0.33966
V5	0.61553	0.61606	0.60105	0.61630	0.38677	0.37104	0.45645	0.48944
V6	0.43864	0.34508	0.37617	0.30839	0.15722	0.17423	0.06832	0.16506
V7	0.51023	0.50371	0.57093	0.54843	0.29192	0.28129	0.36579	0.37021
V8	0.66525	0.72048	0.64215	0.71232	0.48262	0.47203	0.54710	0.62116
V9	0.69381	0.72317	0.68541	0.72156	0.45675	0.44976	0.52588	0.58882
V10	0.70556	0.63633	0.50993	0.54480	0.30550	0.27868	0.33036	0.36055
V11	0.67523	0.62365	0.51125	0.55746	0.26991	0.27562	0.28778	0.35503
V12	0.65694	0.69109	0.65792	0.68460	0.40328	0.41160	0.49563	0.57386
V13	0.68775	0.61814	0.49157	0.52120	0.58534	0.61986	0.49392	0.50383
V14	0.54751	0.56053	0.36661	0.45956	0.57825	0.60003	0.52568	0.51470
V15	1.00000	0.96559	0.84989	0.89718	0.74439	0.74729	0.72344	0.75935
V16	0.96559	1.00000	0.83182	0.93129	0.78867	0.78739	0.80419	0.83925
V17	0.84989	0.83182	1.00000	0.92965	0.76544	0.78905	0.78768	0.81661
V18	0.89718	0.93129	0.92965	1.00000	0.83449	0.83939	0.86608	0.89446
V19	0.74439	0.78867	0.76544	0.83449	1.00000	0.93982	0.91903	0.87398
V20	0.74729	0.78739	0.78905	0.83939	0.93982	1.00000	0.86694	0.91931
V21	0.72344	0.80419	0.78768	0.86608	0.91903	0.86694	1.00000	0.91877
V22	0.75935	0.83925	0.81661	0.89446	0.87398	0.91931	0.91877	1.00000

APPENDIX D-II

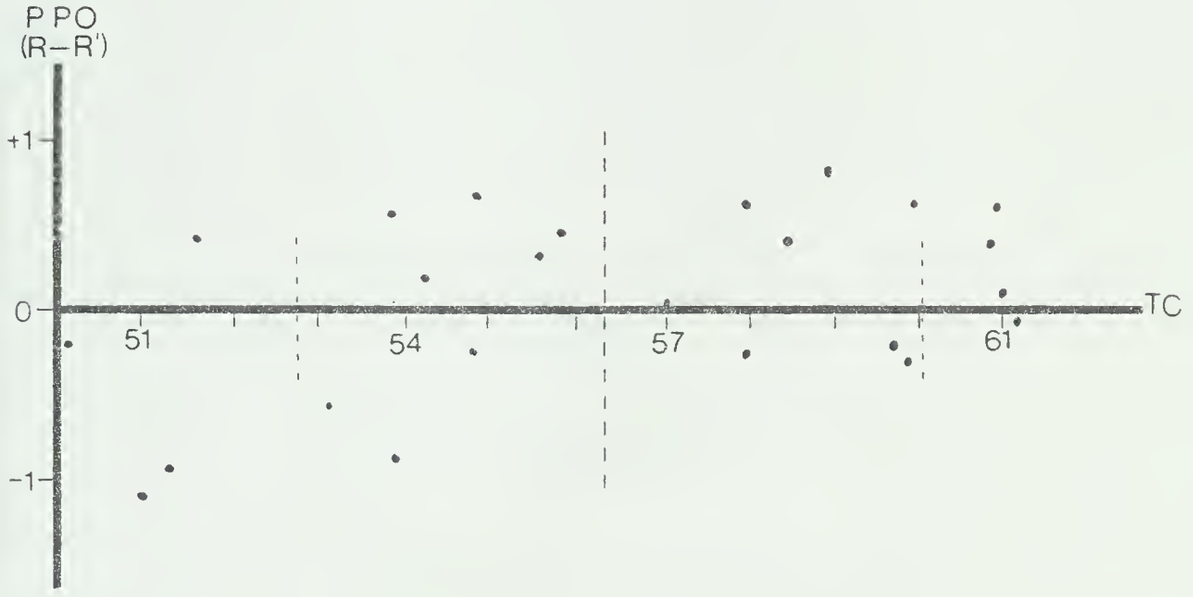
Relationship of Weight to Residual

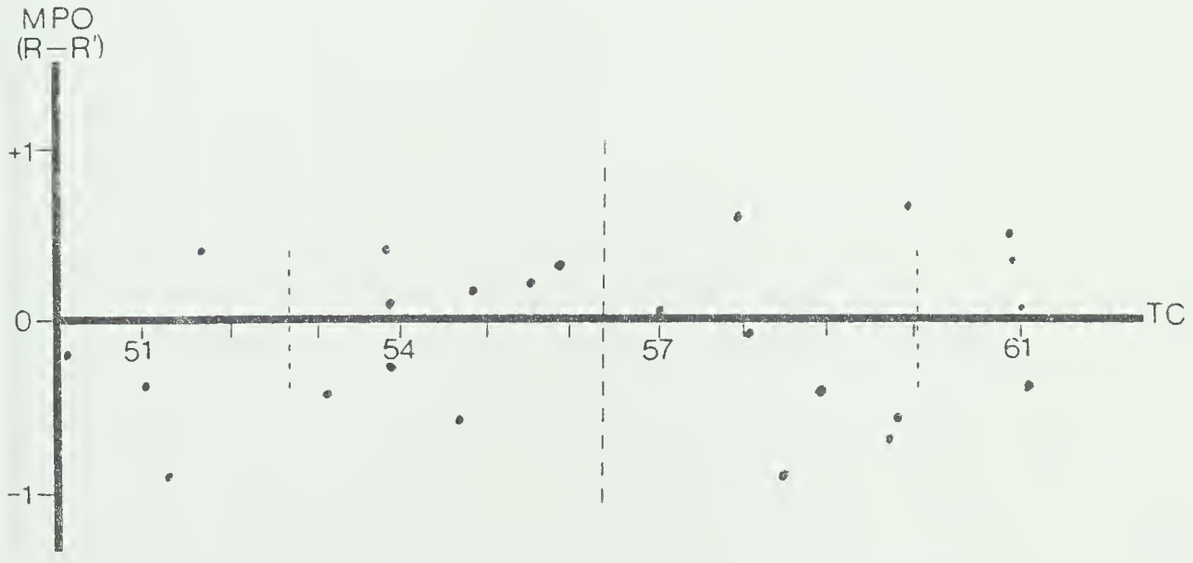




APPENDIX D-III

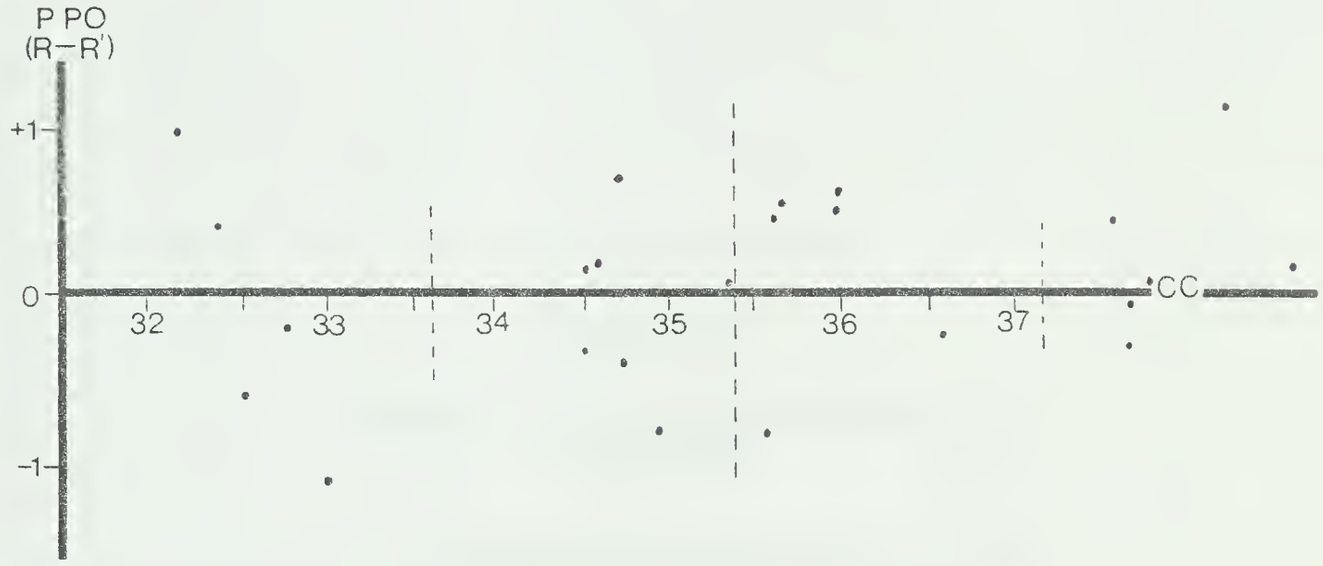
Relationship of Thigh Circumference to Residual

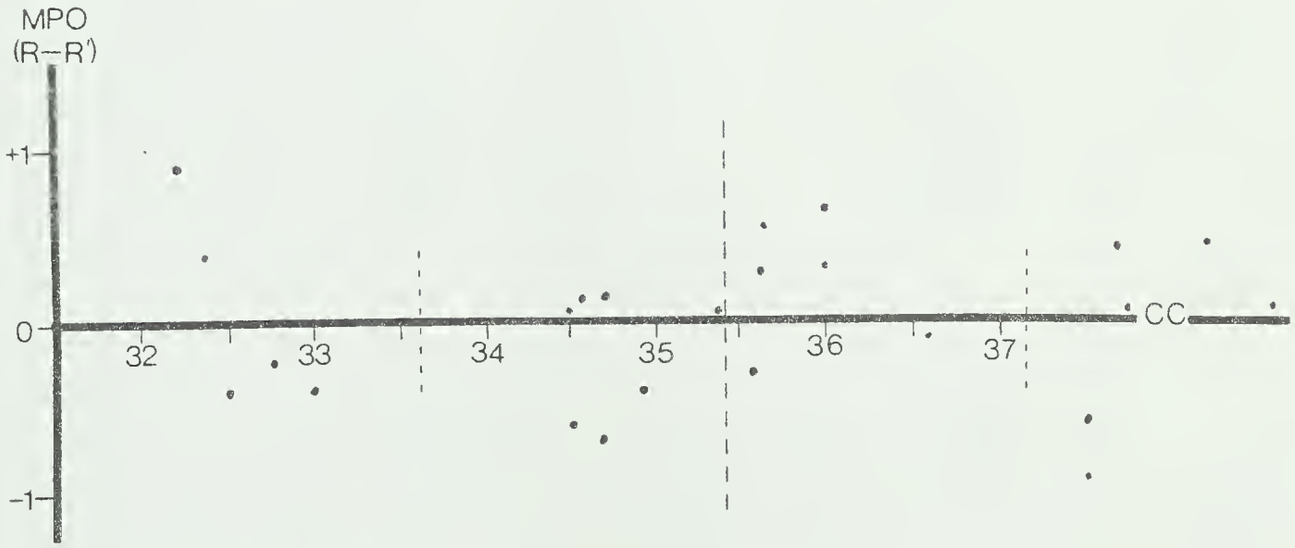




APPENDIX D-IV

Relationship of Calf Circumference to Residual





APPENDIX E

STEPWISE MULTIPLE REGRESSION FOR PPO AND MPO

E-I: Stepwise Multiple Regression For PPO

E-II: Stepwise Multiple Regression For MPO

APPENDIX E-I

Stepwise Multiple Regression for PPO

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* * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                  REGRESSION LIST 11
DEPENDENT VARIABLE..     V10        PEAK

VARIABLE(S) ENTERED ON STEP NUMBER  1..     V5          TC

MULTIPLE R           0.65840          ANALYSIS OF VARIANCE     DF       SUM OF SQUARES        MEAN SQUARE          F            P
R SQUARE             0.43349          REGRESSION                1.            5.87811            5.87811      16.83441     0.0005
ADJUSTED R SQUARE    0.40774          RESIDUAL                 22.            7.68179            0.34917
STANDARD ERROR       0.59091

---------------- VARIABLES IN THE EQUATION -----------------          ------------ VARIABLES NOT IN THE EQUATION -------------

VARIABLE              B            BETA      STD ERROR B        F         VARIABLE      BETA IN      PARTIAL    TOLERANCE          F

V5           0.1334259          0.65840        0.03252      16.834        V7           -0.43504     -0.31155     0.29054        2.257
(CONSTANT)  -2.439518                                                     V9           -0.09216     -0.06106     0.24868        0.079

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

VARIABLE(S) ENTERED ON STEP NUMBER  2..     V7          CC

MULTIPLE R           0.69891 *        ANALYSIS OF VARIANCE     DF       SUM OF SQUARES        MEAN SQUARE          F            P
R SQUARE             0.48848          REGRESSION                2.            6.62373            3.31187      10.02704     0.0009
ADJUSTED R SQUARE    0.43976          RESIDUAL                 21.            6.93616            0.33029
STANDARD ERROR       0.57471

---------------- VARIABLES IN THE EQUATION -----------------          ------------ VARIABLES NOT IN THE EQUATION -------------

VARIABLE              B            BETA      STD ERROR B        F         VARIABLE      BETA IN      PARTIAL    TOLERANCE          F

V5           0.2076834          1.02483        0.05868      12.528        V9            0.29795      0.16606     0.15890        0.567
V7          -0.1721956         -0.43504        0.11461       2.257
(CONSTANT)  -0.5265902
```

APPENDIX E-I
(Continued)

* M U L T I P L E R E G R E S S I O N * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 11

DEPENDENT VARIABLE.. V10 PEAK

VARIABLE(S) ENTERED ON STEP NUMBER 3.. V9 WT

		ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	P
MULTIPLE R	0.70893	REGRESSION	3.	6.81501	2.27167	6.73598	0.0025
R SQUARE	0.50259	RESIDUAL	20.	6.74489	0.33724		
ADJUSTED R SQUARE	0.42797						
STANDARD ERROR	0.58073						

---------- VARIABLES IN THE EQUATION ----------

VARIABLE	B	BETA	STD ERROR B	F
V5	0.1836180	0.90608	0.06735	7.432
V7	-0.2377538	-0.60067	0.14488	2.693
V9	0.3009654E-01	0.29795	0.03996	0.567
(CONSTANT)	1.289891			

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F

MAXIMUM STEP REACHED

STATISTICS WHICH CANNOT BE COMPUTED ARE PRINTED AS ALL NINES.

* M U L T I P L E R E G R E S S I O N * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 11

DEPENDENT VARIABLE.. V10 PEAK

SUMMARY TABLE

VARIABLE		MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B	BETA
V5	TC	0.65840	0.43349	0.43349	0.65840	0.1836180	0.90608
V7	CC	0.69891	0.48848	0.05499	0.42817	-0.2377538	-0.60067
V9	WT	0.70893	0.50259	0.01411	0.54777	0.3009654E-01	0.29795
(CONSTANT)						1.289891	

APPENDIX E-II

Stepwise Multiple Regression for MPO

```
* * * * * * * * * * * * * * * * * * * * * * *   M U L T I P L E   R E G R E S S I O N   * * * * * * * * * * * * *   VARIABLE LIST  1
                                                                                                                  REGRESSION LIST 12
DEPENDENT VARIABLE..   V11        MAX

VARIABLE(S) ENTERED ON STEP NUMBER  1..   V5         TC

MULTIPLE R           0.70064         ANALYSIS OF VARIANCE    DF      SUM OF SQUARES       MEAN SQUARE           F          P
R SQUARE             0.49090         REGRESSION               1.            5.39986           5.39986       21.21319    0.0001
ADJUSTED R SQUARE    0.46776         RESIDUAL                22.            5.60014           0.25455
STANDARD ERROR       0.50453

---------------- VARIABLES IN THE EQUATION -----------------          ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE            B          BETA     STD ERROR B       F              VARIABLE      BETA IN      PARTIAL    TOLERANCE          F

V5            0.1278829      0.70064      0.02777      21.213             V7          -0.20668     -0.15613     0.29054         0.525
(CONSTANT)   -2.075341                                                    V9           0.11238      0.07854     0.24868         0.130

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

VARIABLE(S) ENTERED ON STEP NUMBER  2..   V7         CC

MULTIPLE R           0.70944         ANALYSIS OF VARIANCE    DF      SUM OF SQUARES       MEAN SQUARE           F          P
R SQUARE             0.50331         REGRESSION               2.            5.53638           2.76819       10.63982    0.0006
ADJUSTED R SQUARE    0.45600         RESIDUAL                21.            5.46362           0.26017
STANDARD ERROR       0.51007

---------------- VARIABLES IN THE EQUATION -----------------          ------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE            B          BETA     STD ERROR B       F              VARIABLE      BETA IN      PARTIAL    TOLERANCE          F

V5            0.1596574      0.87472      0.05208       9.399             V9           0.38595      0.21829     0.15890         1.001
V7           -0.7368174E-01 -0.20668      0.10172       0.525
(CONSTANT)   -1.256808
```

APPENDIX E-II
(Continued)

* M U L T I P L E R E G R E S S I O N * * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 12

DEPENDENT VARIABLE.. V11 MAX

VARIABLE(S) ENTERED ON STEP NUMBER 3.. V9 WT

MULTIPLE R	0.72593	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	P
R SQUARE	0.52698	REGRESSION	3.	5.79673	1.93224	7.42704	0.0016
ADJUSTED R SQUARE	0.45602	RESIDUAL	20.	5.20327	0.26016		
STANDARD ERROR	0.51006						

---------- VARIABLES IN THE EQUATION ----------

VARIABLE	B	BETA	STD ERROR B	F
V5	0.1315808	0.72090	0.05916	4.947
V7	-0.1501671	-0.42122	0.12725	1.393
V9	0.3511302E-01	0.38595	0.03510	1.001
(CONSTANT)	0.8624428			

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F

MAXIMUM STEP REACHED

STATISTICS WHICH CANNOT BE COMPUTED ARE PRINTED AS ALL NINES.

SUMMARY TABLE

VARIABLE		MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B	BETA
V5	TC	0.70064	0.49090	0.49090	0.70064	0.1315808	0.72090
V7	CC	0.70944	0.50331	0.01241	0.53010	-0.1501671	-0.42122
V9	WT	0.72593	0.52698	0.02367	0.63525	0.3511302E-01	0.38595
(CONSTANT)						0.8624428	

APPENDIX F

ANOVA AND SCHEFFÉ POST HOC TEST

APPENDIX F

ANOVA and Scheffé Post Hoc Test

VARIABLE	GROUP					
	1	2	3	4	5	6
LEG VOLUME	*	*	*		*	
LEAN BODY MASS	*	*				*
WEIGHT		*	*			
MAX. R		*				*
PPO	*	*	*		*	*
MPO	*	*	*		*	
PPO(WIN)	*	*	*			
MPO(WIN)			*			

* Significant differences found at the 0.05 level

APPENDIX G

CROSS-VALIDATION PROCEDURE

APPENDIX G

Cross-Validation Procedure

PPO(R) = -0.2601 + 0.2208(TC) -0.2287 + 0.0174(WT) (for n = 14)	MPO(R) = 0.8625 + 0.1162(TC) -0.1413 + 0.0452(WT) (for n = 14)
R = 0.84 ($p \leq 0.05$)	R = 0.82 ($p \leq 0.05$)

Predicted R	Actual R	Predicted R	Actual R
5.03	4.75	5.23	4.50
5.29	4.25	4.91	5.00
4.34	3.25	4.42	4.00
5.20	5.50	5.31	5.50
5.90	5.75	5.96	6.25
4.90	5.50	5.08	4.50
4.84	4.75	5.47	5.00
4.90	4.25	4.70	4.25
4.90	5.50	4.60	5.50
4.89	5.00	5.00	5.00

r = 0.63 ($p \leq 0.05$)	r = 0.67 ($p \leq 0.05$)
R - r = 0.84 - 0.63 = 0.21	R - r = 0.82 - 0.67 = 0.15
Shrinkage = $(0.21)^2 .100 = 4.41\%$	Shrinkage = $(0.15)^2 .100 = 2.25\%$

APPENDIX H

LACTIC ACID ANALYSES

H-I: Reliabilities For Lactic Acid Assay

H-II: Pipetting Variability

H-III: Blood Lactic Acid

APPENDIX H-I

Reliabilities for Lactic Acid Assay

	12 MG % STD.	36 MG % STD.	60 MG % STD.
	0.189	0.480	0.840
	0.166	0.485	0.830
	0.167	0.515	0.835
	0.173	0.490	0.800
	0.162	0.490	0.830
	0.720	0.500	0.830
	0.169	0.490	0.830
	0.153	0.500	0.830
	0.162	0.490	0.795
	0.162	0.495	0.835
MEAN	0.168	0.494	0.826
S.D.	0.00954	0.0097	0.0154
CV %	5.69%	1.96%	1.87%

APPENDIX H-II

Pipetting Variability

	0.1 ML	1 ML	2.4 ML
	0.1056	1.0005	2.3986
	0.1002	0.9995	2.3982
	0.1000	1.0001	2.3994
	0.1048	1.0007	2.3926
	0.0998	0.9974	2.3952
	0.0997	0.9969	2.4002
	0.1002	0.9949	2.4228
	0.1010	1.0007	2.4067
	0.1007	0.0054	2.3937
	0.1050	0.9958	2.4086
	0.1044	0.9981	2.3974
	0.1046	0.9952	2.3934
	0.1004	0.9932	2.4020
	0.1033	0.9968	2.4518
	0.1000	0.9970	2.4031
	0.1000	0.9963	2.4066
	0.1071	0.9942	2.4066
	0.0990	0.9963	2.4091
	0.1002	0.99460.995	2.4003
	0.1000	0.9950	2.4020
$\bar{X}$	0.1017	0.9969	2.4044
S.D.	0.0024	0.0023	0.0132
CV %	2.34	0.232	0.550

APPENDIX H-III

Blood Lactic Acid

The lactates of whole blood are stabilized by the addition of perchloric acid. This precipitates protein and the lactate in the protein-free supernatant is converted to pyruvate by the addition of a lactate dehydrigenase (LDH) suspension. The extent of the conversion is determined by the amount of reduced NADH produced using the Spectrophotometer at 340 mu. By absorbance or lack of absorbance of the sample and standards it can be calculated in ml/100 ml of blood the extent to which LA was present in the blood sample.

The following equation represents the reaction:

$$\text{Perchloric Acid} + \text{LA} \xrightarrow[\text{excess NAD}]{\text{LDH}} \text{NADH} + \text{PA}$$

Once the blood sample has been mixed with the reactants it must then incubate for approximately thirty minutes at 37°C or 45 minutes at 25°C. The solution is then ready to be analyzed spectrophometrically. (N.B.: If the samples cannot be assayed immediately they can be preserved up to one month without any detrimental effects if in solution with the perchloric acid)(Lynch et al., 1969).

APPENDIX I

MISCELLANEOUS

APPENDIX I-I

Consent for Anaerobic Power Tests

I, _____, hereby agree to voluntarily undertake a series of 30 second maximal anaerobic power tests on the bicycle ergometer, designed to determine my ability to utilize anaerobic energy sources. I understand that I will perform tests of underwater weighing, and have anthropometric measures and leg volume measures taken. I may also be selected to partake in bicycle ergometer tests that require a venous blood sample to be taken at the completion of the test.

I understand that with any type of exercise test there are potential risks and at any time during the test I experience unusual discomfort I will ask to discontinue the test. I realize that I can voluntarily withdraw from the study at any time. I acknowledge that my training status is of a highly physically active to well-trained status and therefore should be suitably conditioned for such tests.

In agreeing to such an examination, I waive any legal recourse against administrators of the test, from any and all claims resulting from this fitness test.

DATE: _____

VOLUNTEER: _____(signature)

WITNESS: _____(signature)

APPENDIX I-II

PAR-Q Form

Physical Activity Readiness Questionnaire

For most people, physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them. Has your doctor ever said you have heart trouble? _____

Do you frequently suffer from pains in your heart or chest? _____

Do you often feel faint or have spells of severe dizziness? _____

Has a doctor ever said your blood pressure was too high? _____

Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggrevated by exercise, or might be made worse with exercise? _____

Is there a good reason not mentioned here why you should not follow an activity program even if you wanted to? _____

Are you engaged in strenuous physical activity three times per week or more? _____

Resting Blood Pressure? _____

SIGNATURE _____

DATE _____

APPENDIX I-III

Raw Data Sheet

A. GENERAL INFORMATION

Name:_____ Date: _____

Age: _____ Par Q: _____

Weight: _____ Consent Form:_____

Activity:_____ Seat Height:_____

Training Status:_____

B. HYDROSTATIC WEIGHING

Vital Capacity: _____, _____, _____. Mean VC:_____

25% VC: _____

Water Temp(°C): _____ Water Density: _____

Chart Reading: _____, _____, _____. Mean Chart Reading:

_____

C. ANTHROPOMETRIC DATA:

Leg Volume: Pre_____ - Post _____ = _____ litres.

Pre_____ - Post _____ = _____ litres.

Thigh Skinfold: _____, _____ mean: _____

Thigh Circumferance: _____, _____ mean: _____

Calf Skinfold: _____, _____

Calf Circumferance: _____, _____

D. LACTATES:

Test 1 _____, _____

Test 2 _____, _____

Test 3 _____, _____

Test 4 _____, _____

Test 5 _____, _____

Test 6 _____, _____

E. ANAEROBIC POWER TESTS

Res.	Time(secs)	5s	10	15	20	25	30	Total P.O.	Mean P.O.	Peak P.O.
Room Temp. =	RP/5sec									
	KP/5sec									
	Watts									